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ABSTRACT

This study develops and employs the construct, personal orientation to science learning, to study the processes by which children construct meaning as they learn science in school. The theoretical bases of the thesis are the commitments of a constructivist view of learning and the psychological framework of George Kelly's Personal Construct Theory. Methods appropriate to these theoretical foundations were used in the collection of information. These were: participant observation; a dialogical approach; an attitude of sensitive listening; stimulated video recall; and an adaptation of Kelly's Repertory Grid Test. Ongoing evaluation of idea development was also conducted with the six fifth-grade children in a selected study group and with the students in the classroom as a whole. Themes of personal orientation to learning emerged in the analysis of data and were used to revisit each child's science learning experiences. Guidance is offered for teachers interested in a serious consideration of the meaning of a constructivist view of the learner in the classroom. Suggestions are also made to assist teachers in the selection of experiences and curricula which will help students to become aware of their own orientations to science learning and how they might take greater responsibility for their own learning. (MVL)

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WHAT CHILDREN BRING TO LIGHT:
A STUDY OF PERSONAL ORIENTATION TO SCIENCE LEARNING

BY

BONNIE L. SHAPIRO

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

IN

THE DEPARTMENT OF ELEMENTARY EDUCATION

EDMONTON, ALBERTA
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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled, "What Children Bring to Light: A Study of Personal Orientation to Science Learning," submitted by Bonnie L. Shapiro in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Elementary Education.

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In Memory of

My Father,

Hyman L. Shapiro

Abstract

This study develops and employs the construct, 'personal orientation to science learning' to study the processes by which children construct meaning as they learn science in school.

Over a period of six months, I was present in a grade five classroom, and engaged in ongoing discussions with six students in a selected study group, three boys and three girls. Two of the students were considered by their teachers to demonstrate superior academic ability, Two students were considered to be of average ability, and two students were experiencing extreme difficulty in all of their school endeavors. Classroom interaction and idea development of the children in the study group was carefully observed and recorded as the class learned about the topic light.

The theoretical bases of the thesis are the commitments of a constructivist view of learning and the psychological framework of George Kelly's Personal Construct Theory. Methods appropriate to these theoretical foundations were used in the collection of information. These were: participant observation; a dialogical approach; an attitude of sensitive listening; stimulated video recall; and an adaptation of Kelly's Repertory Grid Test. Ongoing evaluation of idea development was also conducted with the six children in the study group and with the students in the classroom as a whole.

Themes of personal orientation to learning emerged in the analysis of data and were used to revisit each child's science learning experiences. Case study reports were then constructed to present paradigmatic instances which demonstrate each child's personal orientation themes. These snapshot portayals show that personal orientation to science learning affects what students find of value in learning, how they view themselves as science learners, and how they interact with other learners and with their teacher. Outcomes of learning, such as idea change also appear to be affected by students' personal orientations to science learning.

Several levels of implications are suggested by the case study reports. Guidance is offered for teachers interested in a serious consideration of the meaning of a constructivist view of the learner in the classroom. Suggestions are also made to assist teachers in the selection of experiences and curricula which will help students both to become aware of their own orientations to science learning and how they might take greater responsibility for their own learning. In the final chapter a framework for developing and analyzing teaching strategies and activities, 'Experiences to Promote Reflexive Awareness and Self Organization in Science Learning' is presented and discussed.

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Chapter 1

CONCERNS OF THE STUDY

When I heard the learn'd astronomer,
When the proofs, the figures, were ranged in columns before
me,
When I sitting heard the astronomer where he lectured with
much applause in the lecture room
How soon unaccountable I became tired and sick,
Till rising and gliding out I wander'd off by myself,
In the mystical moist night-air, and from time to time,
Look'd up in perfect silence at the stars.

Walt Whitman in Leaves of Grass

1.1 Difficulty in Science Learning: "Weakness" or Window?

Walt Whitman's poem exemplifies a dilemma and a concern for science educators. Here is the student, attracted to a lecture, apparently interested in and wanting to know about the universe. Yet, when confronted with the instructor's systematic presentation of "proofs, figures, charts and diagrams," he recalls, "How soon unaccountable I became tired and sick." Empty. He is sickened and leaves. And in this leaving we feel a profound sense of relief. But for some science educators, this student's experience is not counted as a valid one.

Isaac Asimov (1985), foremost writer and popularizer of science, argues that in this poem Walt Whitman is "talking through his hat, but the poor old soul didn't know any better" (p. 169). In Asimov's view, Whitman ignores the beauty and sense of wonder which is to be gained through the lecturer's presentation, suggesting that those who cannot 'stomach' such an approach are missing out on the true splendor and wonder to be gained in a study of the universe. For Asimov, the accumulation of factual knowledge in science is the best approach to real appreciation of the amazing patterns and beauty in the universe. According to Asimov, "the poor old poet never knew what a stultified and limited beauty he observed when he looked up in perfect silence at the stars" (p. 170). But Whitman's poem may not be debating which isis the superior knowledge and beauty, a direct, personal, mystical experience of wonder or the experience of possessing a great depth of knowledge through accumulated facts. Perhaps it is Asimov who is missing the point of the poem by his unwillingness to consider the reality of the experience of the student who is attempting to make sense of the science lecture.

The problem Whitman brings to our attention through this poem is that the scientists' understandings can crush the initial joy and wonder which prompts the desire to learn about natural phenomena. If we are willing to listen carefully to this individual's experience, rather than condemn it as a weakness, it may, like a window, open our understanding of how it is that the process of this student's education in science has turned him away from formal study. To understand students' difficulties, frustrations and joys as they learn science, perhaps we must listen more to the interpretations of science, and of science learning from the students themselves.

1.2 The Purposes of the Study

The central purpose of the research project has been to refocus attention upon and attempt to understand the individual learner's pursuit of meaning during the everyday experience of learning science in the elementary school classroom, the place where young children are formally initiated into an understanding of scientists' science. Two general questions have been asked throughout the study:

1. What is the nature of individual children's approaches or orientations to science study in the elementary school program?
2. How do students' approaches or orientations to science study affect and interact with the formal presentation of knowledge in the school science classroom?

A second major purpose of the study has been to pursue the question, how may we best understand and convey the nature of the child's approach to the study of phenomena and meanings which individuals attribute to science study? The study attempts to use a blend of research approaches to convey these individual experiences.

The research was undertaken with a study group of six students during a grade five class's initiation to the study of the topic, light. The project has, therefore, allowed the children to comment on their personal viewpoints while undertaking a study which is immediate and present to them. More specific questions provided focus in the development of case reports:

1. What are the children's ideas about the nature of light prior to the study?
2. What are students' previous experiences of and interest in the study of science in the elementary school program?
3. What are the children's ideas about the meaning and value of the study of science?
4. What are the children's views of themselves as learners of science?
5. What aspects of the study of the topic appear to be readily comprehended or accepted? What do students see as facilitating their understanding during the study of the topic, light? What types of learning activities are considered most valuable?
6. Do the children experience puzzlement, difficulty or confusion during the study of the topic light? What do the children say about the difficulties which they encounter?
7. How does the child's approach or orientation to science study interact with the acquisition of ideas?

1.3 The Research Approach

A "constructivist alternative" approach (Pope, 1981a) is the foundation of the philosophical stance of the research project and guides the collection of information, conversations, reflections upon the experiences and observations, and the presentation of the project. The constructivist alternative viewpoint is exemplified in the work of George Kelly (1955) and other psychologists, educators, and philosophers (Pope, 1982; Gilbert and Watts, 1983; Dewey, 1913; Magoon, 1977). George Kelly argued that we might best understand how the individual person views his or her experience, by seeing the person not as a set of drives or responses acting upon the universe, but as a person who views the world in his or her own unique manner and whose view has individual integrity. The dynamic argument of this viewpoint for educational research and practice is that in planning for teaching, recognition and high priority should be given to students' ideas, language, beliefs, and expectations, as these personal meanings are the bases upon which the student creates meaning during instruction.

Personal Construct Theory was invented by George Kelly (1955), as an attempt to integrate a theory of personality with a theory of knowledge. Kelly considered each person to be an "intuitive scientist," formulating hypotheses about the world, collecting data that confirm or disconfirm these hypotheses, and then altering his or her conception of the world to include this new information. In this way, every person operates in a manner similar to the scientist, even though the term, scientist does not preclude other types of orientation, for example, an entirely aesthetic orientation to science learning. The individual is thought to act "like a scientist" in that each person operates in the world on the basis of his or her own anticipations, expectations, theories or assumptions concerning the world and his or her own circumstances.

1.4 Focus and Duration of the Project

Over a six month period I was a very welcome observer and participant in Mr. Ryan's grade five classroom. I was present extensively as students studied all subjects in their curriculum program with Mr. Ryan and other teachers, and was present during all lessons in which the children studied science with Mr. Ryan. Mr. Ryan graciously extended the privilege of allowing me to observe and scrutinize his work in the school. He told me that he welcomed the opportunity to reconsider his own work in light of my study. The children in the classroom also allowed me to enter into their lives in a way that was beyond my greatest expectations, as they shared with me their thoughts and feelings about school and science study.

Though several science topics were undertaken during the time which I spent in the classroom, children's study of light phenomena constituted the content focus of my study. In conducting the project, I established a close relationship with all of the teachers and children of the grade five class, but more intensely with a small group of six children. Listening to, talking with, and being with the children in the study has been the essence of the research approach. The research project attempts to present to the reader snapshot portrayals of childrens' interests in, anticipations of, and expectations for science study through the analysis of individual experiences during the study of a specific science topic.

1.5 The Need for the Study: The Neglect of the Existential World of the Learner

> Emphasis upon the person-as-meaning-maker is a dominant theme in educational theorizing, but in practice, the phenomenological world of the learner is often neglected.
>
> Pope, 1982 p. 8

Echoing Pope, Brophy (1982) asserts that "For the most part, educational researchers have considered students only as objects of teacher activity." He states further: "a complete account of classroom events will have to include, besides information about teacher behavior and its long-term effects, information about what students are doing in classrooms and how these activities affect their perceptions, knowledge and beliefs" (Brophy, 1982, p. 519).

Though much has been said of the value of collecting information of the latter type, little research in education has actually been undertaken to document and convey such insight. In 1984, the Science Council of Canada released the results of its three year study of Science Education in Canadian schools. This three volume report provides description and analysis of teacher and observer perceptions of classroom teaching and of curriculum projects through the presentation of survey results (Orpwood and Soque, 1984; Orpwood, Alam and Soque, 1984) and case study descriptions (Olson and Russell, 1984). Student perceptions of science learning and their approaches to meaning-making received some attention in the case study reports, but the focus and emphasis of the reports is largely upon the effects of teacher approaches. In fact, very few research studies have explored students' perspectives on the experience of science learning in the context of the natural setting of the classroom.

1.6 What is At Stake in the Attempt to Understand the Reality of Student Difficulties in Learning Science?

The 1981-1982 National Assessment of Science project, *Images in Science* (Hueftle, et al. 1983), reported that in a survey of students' attitudes towards science,

> ...fewer than half of the 13-year-olds thought that their science classes were interesting, easy or comfortable to be in. Disappointingly, 73 percent said they were sometimes, always or often bored in their science classes, and a majority said they didn't like to go and felt unsuccessful. A majority reported that subjects in science were too difficult.
>
> p. 54

The project also reports that although a majority of students felt positively toward their science teachers, and towards the possibility of pursuing careers in science, over 61 percent of students reported that they were sometimes or always afraid to ask questions in science class. In addition, fully 67 percent of students stated that science classes sometimes or always made them feel stupid. Though nearly 80 percent of students agreed that "the things you learn in science classes have nothing to do with the real world, over 74 percent agreed with the statement that "much of what you learn in science classes will be useful in the future." What is it that happens during science classes in the early years of a person's education which causes such negative and inconsistent images to emerge so strongly?

Why is it deemed critical that this question be explored? Students are turning away from science, both as a career choice, as an area of valuable potential insight into daily personal and political decisions, and as an area of study in which one experiences the sheer excitement and sense of wonder in the deep understanding of the mystery of the natural world. In the United States, fewer than 10 per cent of precollege students profess a genuine interest in science, with approximately only one quarter of these students actually going on to pursue careers as professional scientists (National Center for Educational Statistics, cited by Shamos, 1984). Though not everyone will become a scientist, an understanding of the basic ideas of science is essential for anyone living in our world, for we must make daily decisions which may enlighten or burden our society depending on our ability to use information effectively. Hurd concluded that in 1984 high school students were generally not empowered with the ability to identify and reasonably interpret a science/technology-based personal or social problem (Hurd, 1984). The National Assessment in Science Project (Hueftle et al. 1983) states that by the time U.S. students leave grade 10, half of them have already finished the major portion of their science education.

Our understanding of the young learner's experience in the classroom is less well understood, though it is believed that attitudes which are formed about science and science learning crystallize in the years before students even enter high school (Hueftle et al. 1983).

For many children the experience of learning science is one of daily confusion and difficulty in constructing meaning in their studies. Few research studies attempt to give insight into the meaning and value which students attribute to science study. Little attention is given to such questions as, What do young students find interesting in their studies? How do they come to accept explanations? What resources and strategies do they use for learning? or Why is it that they seem to reject some ideas or even science altogether?'

Instead, it seems that in the name of improvement of science instruction, the complaint most often made is that students do not acquire a sufficient amount of content information. Concern for the number of specific facts which students possess has often been greater than the concern for the child's interest in and understanding of the subject matter. In fact, much of the understanding which students do hold remains hidden from us because our methods for progressing "through the curriculum" and assessing student understandings are shaped by the demands of expediency and our culture's press to continually quicken the pace of activities (Elkind, 1980).

If it is true that attitudes about science and science learning are crystallized even before high school, then it is important that we reconsider the ways that formal instruction in science takes account of the experience of young students. The pre-high school experience of science learning may encourage a student to delight in and persist in continued study, or may cause discouragement, or distrust of his or her own insights to the extent that the student may come to fear or to reject science.

Some students may feel afraid to ask questions, or may learn that some types of questions are "safe" to ask, while others must not be voiced for fear of being seen as wrong. Students learn that success in achieving the correct answers to problems is sometimes more highly valued than concept understanding. "Have I got the right answer?" may be seen as a more important question for some students than "Do I understand this?" The intellectual dishonesty of this approach (Driver, 1975, 1984; Wellington, 1981) leads students eventually to express feelings of alienation, isolation, and non-involvement regarding experiences in science courses. This attitude may extend to eventual distrust and resentment towards the enterprise of science in general, and towards future involvement in any task which appears to require science knowledge.

According to the National Assessment in Science Report, (Hueftle, et al. 1983) at the same time that many students show a fear of formal science study, many view, with intense interest and curiosity, the scientific and technological achievements which are immediate and present in their world, wanting to know how these achievements affect their daily lives. Despite the clear evidence for this great interest, the overall picture of learning in science portrayed in the NASR report is one of "waning science achievement," coupled with "eroding student attitudes" towards science (Hueftle et al., p. 98). That the sincere desire to know is sometimes thwarted early in the child's educational experience must be detrimental to the quality of the child's school experience and ultimately to the quality of life in our society. Interest and delight in the study of natural phenomena are vital if the student is to be encouraged to persist in learning.

Given the option, the student in Whitman's poem may never return to a science lecture room again. What is the solution? Lock the door of the lecture room? Ignore the experience of despair and pain expressed by the individual student and label it as weakness? Or does the answer lie in our efforts to listen to students so that we might understand what it is like for the learner who is attempting to learn science?

1.7 The Research Quest

The present research project has been built upon an interest in the latter question. What, then, is the best way to understand the meaning and impact of the school initiation to science learning for young children? This project has been a serious attempt to develop an approach to listening which investigates the meanings which young children attribute to the experience of science learning as they are studying a topic in their classroom. The project has led me to become an anthropologist of classroom culture, as I realized that I would be both embedded in the children's experience and culture and am yet a distance from it. To allow the children themselves to speak with me about their experience required an approach which permitted a focus upon individual children learning in classrooms. In this search I discovered, in the work of George Kelly (1955) the clarification of an attitude towards researching the person, not as "subject" but as "individual person." Kelly describes and refers to this approach as listening with a "credulous attitude." It takes very seriously the view that what persons themselves have to say about the experience is an important, valid, and valuable source of information to be taken seriously into account. I found in this approach a set of tools and a basic philosophy for reflecting upon and reconsidering the ways that we initiate children into science learning.

Chapter 2

FIRST STEPS, CONVERSATIONS, READING, AND REFLECTION: EXPLORATORY WORK AND THE FORMULATION OF THE RESEARCH APPROACH

2.1 An Overview of the Exploratory Studies: Focus and Purposes

The purpose of Chapter 2 is to enable the reader to follow my journey of exploration, reading, and reflection in formulating the research project and to understand the basis for the major decisions made in the development of the study.

The first step taken in the attempt to understand the young childrens' experience of science study involved visiting elementary classrooms to participate with, talk with, and observe children and their teachers. Participation in several science learning settings allowed me to reflect on the goals and direction of the project close to the actual experience of young children learning. In these settings I was also able to consider what might be the best approaches for recording and conveying childrens' experience.

During a six month exploratory period, I made regular visits to six classrooms. The range of settings which were visited included a four/five split grade in a self-contained classroom, a grade one self-contained classroom, a grade five self-contained classroom, a grade four open area classroom, classes of students in grades two to six in a bilingual school, and a self-contained grade six class.

Initially, this exploratory work consisted of observation, structured interviews and informal conversation with students and teachers, usually during science lessons. In several settings I was able to visit for an entire day and followed students through all of their school experiences. At the beginning of this period I had several questions in a variety of potential research topic areas. For example, I was concerned with the nature and quality of children's opportunities for participation in the science program. Several other questions emerged during reflection on my visits. I did not limit or censor the type or number of concerns which were coming to mind at this time, but kept a record of my thoughts and questions. Some of the other kinds of questions that I considered are the following:

1. To what extent will students of various ages be able to talk with me about the meaning of their learning? That is, to what extent will the children be able to recall and reflect upon their own learning processes and experiences?
2. What types of opportunities exist in typical science classroom settings for students to talk about their ideas concerning the nature of natural phenomena?
3. What are the factors which inhibit student talk in the science classroom?
4. What are some of the factors which encourage student talk in the classroom?
5. Is there a relationship between student involvement through talk about a topic and student interest in the

topic?

6. What does it mean to be interested in a science topic?

7. What are the ways that children use language to learn in the small group setting?

8. Are there differences in the ways that children use language to learn in large group settings as compared to small group settings?

9. What are the children's understandings about the topic which they studying? What are the links between student understandings and areas of difficulty for students?

10. Are there groups of children who experience learning differently than others? Can they be identified in some way?

11. What is the nature of the student's initiation to the experience of science learning in the elementary school? What sorts of views of science itself do children develop in the elementary school program?

2.2 Exploratory Observations: Some General Observations About Classrooms

During this initial intense observation period, I was impressed by what seemed to be the strong influence of classroom teacher's overt and tacit rules regarding students' verbal interaction with the teacher and with one another during the lessons. Reviewing my notes, I found that in some settings the classroom teacher's speech and action were dominant. Other settings were characterized primarily by observations of the students in the classroom working with and speaking with one another. In one of the latter settings, learning centers were in use. Here, the teacher intervened usually only to address a problem which an individual might be having, or to have an individual conversation with a child. It seemed that in this type of setting, the teacher not only was able to speak with and work with the children individually, but the children seemed more involved and interested in what they were doing, and had far more opportunity to speak with one another.

It was also during this initial period of observation that I was able to speak with children about their understandings of the various tasks which they had been assigned. It became clear through sitting and talking with children that in many cases, when it had appeared to the teacher that the class as a whole understood an idea or direction, many individuals, in fact, did not. In these cases, the teacher's conclusion about student grasp of ideas appeared to be based on one or two individuals' correct responses to a question which had been directed to the entire class. Because one or two children were able to respond correctly, the teacher assumed that the majority of class members also understood the idea.

In one setting, I sat with Neil. Students in his grade five class were asked by their teacher, John Bell, to look up "a fact about the human body." A number of resource books were made available for student to use to complete the task. I noticed that Neil seemed to be avoiding the task. In speaking with him, I discovered that not only did Neil not know what a fact was, he did not know how to use a book index. Adding to his frustration was the fact that the resource book he was using had been written for high school students. Neil seemed quite helpless and was obviously not interested in the task presented to him. His inability and lack of interest in understanding seemed to be almost a strategy. It was as if he believed that perhaps I might do the task for him. Some educators have referred to such behavior as a "learned helplessness" (Seligman, 1975), a strategy developed by learners when tasks repeatedly seem very difficult. Neil glanced frequently at the clock. He was obviously more interested in having the period over than in understanding what he was expected to do. When the period was over he would not have to give any more thought to the task. I wondered about the importance of interest and understanding for this student. Did Neil approach all learning experiences in the same way or only those which required reading? How did Neil conceive of and value his own learning? What kinds of learning experiences did interest Neil? Was Mr. Bell aware of these? I discovered and read John Dewey's (1913) work Interest and Effort in Education, and explored other aspects of student interest in learning (Jersild, 1949; Whitty, 1963; Callan, 1983). For a time during this period, I considered aspects of student interest in science as a possible focus for my study.

In this fairly typical classroom, the teacher's time was consumed in the planning of activities for students. There were so many activities of short duration, 15 or 20 minutes, which students seemed rushed to, rushed through, then on to the next. There was interest and excitement every time the students physically moved from place to place. Here they had a chance to say something to a friend as they walked down the hall to his music class. But there seemed little real deep experience in the learning activities which had been planned for the children. The teacher also had little time to pause to reflect on the experiences which the children were having. He did not ask them to share their findings at the end of or during this activity, nor did he use any means to evaluate how valuable or educative the experiences actually may have been for the children. Mr. Bell was certainly not incompetent, nor was he atypical. He was not uncaring. But he seemed to feel that if he did not keep pushing the students through each activity, boredom and distraction would result. After several conversations with Mr. Bell, I realized that he, like many teachers, was not aware of what did interest his students, or what they were actually accomplishing in their activities. Because science is taught so infrequently, to teach it in such an atmosphere of hurry seems doubly tragic. In addition to the difficulties which children have with the grasping of concepts, they are developing and dealing with views about science itself, about science learning, and about themselves as science learners over the course of their elementary school program.

In another classroom, I had the opportunity to observe and talk with students in a four/five split grade class. Their teacher, Carla Johnston, offered students science every day for the first hour of the morning. She felt that she was very fortunate to be able to use the science/art room every day, because the room was in very great demand as an art room.

Carla's class was composed of the "top" grade four students in the school and a group of average to above average grade five students. All of the children had also been selected on the basis of strong social and interpersonal skills and their ability to work independently. Carla told me that there were no real problems with discipline with this group, and that she believed that she had an "ideal" teaching situation. Carla told me that she considered this daily hour a science/language period, and said that she always taught science and language together. She told me that she strongly held the view that science meant putting ideas together using language and that science and language should be integrated.

The children were making solar collectors on one of the mornings that I visited them. The activity was part of the grade four energy education program. On one board in the classroom, the teacher had written some questions about the solar collector for the grade four students. On a second blackboard she had written a different set of questions for the grade five students. She very deliberately went over the questions on the board with each group. She encouraged the students to remain "on task" and often used this phrase when asking students to get to work. There was a great deal of teacher direction in this initial portion of the presentation, with little input from students.

All of the materials for the lesson had been organized in advance by Carla and were placed on the students' tables before their arrival in the science room. Each student was to make his or her own individual collector, by following textbook directions. Carla had reviewed the directions with the class, pointing out potentially troublesome areas. In particular, she had mentioned the importance of the creation of a hole that was to be made in the box, over which a thermometer would be placed and taped. Carla also mentioned the importance of the overhang on the boxes, demonstrating this with a model house which had two overhangs. She pointed to these and described their purposes in a hot climate.

The presentation portion of the lesson was completed by asking the students if they recalled what had occurred during the last period when many students had not followed directions during the construction of wind turbines.

"They didn't work," one child contributed.

"Mine almost worked," said another.

Carla responded, "Almost is not good enough. Now be sure to follow the directions."

The children began work on their solar collectors. Carla insisted that there be no talking during the activity. When I spoke with her at recess, she told me that she felt that it was important for the children to be silent during the work period so that they would "attend to the task at hand," and give careful, individual attention to their work. I recalled that when I had observed Carla's class two years ago, at that time she had also expressed this view as a basic aspect of her philosophy and as an important aspect of the behavior which she expected in the classroom -- "no talking during the work period." During that lesson I recalled observing students working in a group, moving from learning station to learning station, observing examples of animals in various stages of development. Carla had insisted that the students not discuss any of the animals with one another. At that time, she had also stated to me that she believed that "any extraneous talk hampers students' focus on task."

Reflecting on this classroom and upon my own experience as an elementary school teacher, I often thought about those children who rarely spoke in class. Is it truly educative for students to be so constantly reminded that speaking is not a "good" thing to do -- that one is not "being good" when one speaks in class? There are great gaps in educators' understandings of the role of talk in the child's involvement, interest and effort in learning in science.

Of course, there were several children who ignored the admonition, despite the fact that they were reminded often. The negative effects of being encouraged not to speak have been documented in a variety of psychological studies of shy children whose emotional and cognitive development can be further hampered in the classroom (Zimbardo and Radl, 1982; Stockdale, 1979). I sat with several groups of students who persisted in talking when they had been asked not to by Carla and found that they were, in the majority of cases, speaking about the animals that they were being asked to observe.

Carla had several ways of asking the children to be quiet during science. She would say, "The noise level is too loud, class. This is unacceptable." Or she would direct her attention to an individual by going over to him and saying his name. She indicated to groups of children who were talking that they were out of order. She would look in their direction, lightly snap her fingers, and shake her head in a 'no' fashion.

Carla was constantly smiling, even during these gentle reprimands--perhaps the smile would disappear briefly during a more severe admonishment, but she then quickly resumed the lesson as if nothing happened. I never saw her become truly upset; it was as if she were simply reminding the children of something that they already knew that they should or should not be doing. There appeared to be an unspoken agreement between the teacher and the students that showed a deep mutual respect. The children in this class did not argue with Carla--they simply went back to their work.

Several of the children completed their solar collector boxes quickly. They were then encouraged to help others complete theirs. Those who finished early were delighted to do this, and those who had not finished were also very happy to have the help. I wondered how the students viewed the assistance of fellow students as peer teachers at times during lessons, and how the interaction with peers may have added to their understanding and interest in the topic being studied.

Many of the students spent an inordinate amount of time making the required hole in the box. This had to be accomplished with blunt ended school scissors and was unexpectedly difficult for students.

Jeremy showed me his solar collector and asked me to comment on it:

Jeremy: What do you think of this? Do you think that it should sound this way when I hit it on the side?

Ms. Shapiro: Hmmm. I'm not sure that it should really have any particular sound. A lot of people are having trouble making the hole there for the thermometer. How did you make yours?

Jeremy showed me his method. He had punched the center of the hole first with his pencil and then edged the scissors into the hole.

Jeremy: You're a science teacher, eh? You know, we knew you were coming but we were all expecting a boy!

This comment was not surprising as the stereotypic image of the scientist and even of the science teacher as male is still quite strong among young children, despite recent efforts to broaden this view. I wondered how this attitude might affect a student's self concept as a science learner, and how continuing ideas such as these influence consideration of possible future coursework or a career in science. Would views such as these affect and interact with interest in science learning?

There came a tremendous pressure from Carla to complete the project in time as the class had to leave the room by 9:50 a.m. so that the next class could use the science room. The children were encouraged, prodded and pushed to finish, and they did! Completed boxes were placed on a shelf in the science room, then the class rushed down the hall to their home classroom.

Back in the homeroom classroom, Carla had already written instructions for the grade four students' reading assignment. On another board were instructions for the grade five students' reading assignment. She whispered to me that I was about to observe "a little division of labor," as she would attempt to teach both groups during the same time period. She gathered the grade five students around her on the floor. As she did so, I glanced around the classroom. It seemed cold--in two ways. The temperature was considerably lower in the classroom than in the hallway and in the science room, and the classroom looked in some ways quite unfriendly. It was disorganized and untidy at first glance. A chair sat upside down on the round table in the middle of the room and remained there all morning. I wondered what the children's views might be about the type of environment which allowed them to do their best work. I wondered if their views on the physical arrangement of the classroom made some rooms more conducive to learning than others.

Carla was standing at the blackboard. She ran her hand silently along the written lines on the board which indicated an assignment for the grade four students. As she did so, she looked enthusiastically at the children, smiling at them while running her hand along the line. I was struck with the energy of this teacher and her obvious enthusiasm for teaching. The children appeared to respond to her inviting attitude and warmth. I had noticed this when first observing a student teacher in Carla's classroom previously two years ago, and recalled the verve in her classes at that time.

At recess, Carla told me that although the split class was a delightful group to work with, she often sensed jealousy when she appeared to spend more time with one grade level than the other. She said that the grade five students insisted that they never do what the grade four students were doing, which meant that she had to keep "on her toes" at all times. I noticed that the difficulty coordinating the efforts of the split grade were especially apparent in the reading and spelling programs which was offered. The two grade levels still did quite a bit together during the day, however, in their Science, Music, Physical Education classes and in class discussion periods.

During the recess period we had some time to discuss Carla's science program. She told me, "My whole theory is that the language arts should not be taught as a separate topic--it should be integrated with science and social studies. You see, then the children are involved all day long in 'finding out.' They are coming to know all the time through language. Because we do science every day, by the end of the year my kids really think that science is just the greatest. And I'm really keen on it and excited by science, and that makes all of the difference."

The children truly did respond to Carla warmly and with enthusiasm. However, I could not reconcile the importance which Carla placed on language with the lack of actual use of language by the children which I had observed in several visits to her classroom. The classroom was very strongly dominated by the teacher. In addition, we had not discussed the performance of any specific children nor the special needs of any particular child. And yet, a visitor to Carla's classroom could not help but be enthusiastic about the lively environment which she created for her students.

I had had the opportunity to sit with and talk with individual children in Carla's class as they were learning. Of course, a classroom teacher would not be able to manage this type of individual attention unless a learning center or individualized approach were used. From my perspective as I worked with individual students, I had been more conscious of the effects of the teacher, the classroom and other students, on the experiences of individual students. Though observable tangible results are often considered highly desirable in school systems, these results are often more indicative of success than of understanding. Educators who encourage and permit children to work through difficult problems and relationships for themselves, who permit children to have experiences and encounters which cause them some "dissonance," seem to work so much harder for less than immediate, observable rewards. Oldham (1982) explored the dilemma of the experience of "difficulty" in the high school biology program. She put forth the argument that, in our culture, we may lose a great deal by giving little value to the experience of difficulty. It is through working through our difficulty that we learn and grow. In schools we see difficulty as something quickly to be disposed of, and many children learn to be ashamed that they are having difficulty. If we show our children that we value this experience, that it is important in a person's growth, perhaps there would be less shame and more encouragement to succeed for those who encounter difficulty. If teachers contemplated this dilemma differently, perhaps they would be able to identify the person who is experiencing difficulty more readily, and would have more to offer to that person. Carla's remark to her class, "almost is not good enough," though not intended to be demeaning, subtly conveyed the idea that the experience, the process of learning, was of less value than the outcome. I wondered, do we rob our children by promoting this attitude? How do students interpret remarks such as these?

Twenty minutes after recess was over we were off again, out of the classroom, walking towards the library. A poster on one of the bookcases read, "There is more to life than making things go faster and faster." It seemed so appropriate a reminder in the school environment. Through involvements with many classrooms throughout the past eighteen years, I have come to see schools as places where children and teachers are hurried in so many ways. Why was it important that children have a truly deep experience or involvement with their learning? Is it that we feel uneasy without the tension and false sense of motivation that hurry creates? What is the value of concentrating on the processes of student learning? Is it that educators do not know how to provide this for the child, or have we ourselves become so habituated to hurry that it has become a habit?

2.3 Formulating the Research Approach and Topic

It was at this point in my reading and exploration in classrooms that I realized even more strongly the need to provide information about the process of learning science which went beyond the usual focus on outcomes and outward appearances of successes in grasping the scientist's views of the nature of phenomena. So little information appeared to be available on the child's processes of learning, of the learner's experiences and interpretations in his or her efforts to understand. I felt that this perspective could offer insight for teachers, student teachers, researchers, and potentially learners themselves. This work would help educators to understand how they might more meaningfully assist students in their own efforts to grow and develop in science. The best approach for documenting and conveying this insight appeared to be to work closely with individual children as they learned about a specicific science topic, asking them to help me to make sense of the material and activities which were presented to them.

As my observations and reading progressed, I envisaged a study which would describe the ongoing experiences of several children as they learned about a specific topic in the science program.

2.4 Selection of the Science Topic

During the latter portion of the exploratory period, I selected the topic, light, as a focus for out-of-class interviews with small groups of children. I wanted to uncover some of the ideas which children held about light as very little work had been done on this topic area. I began a review of the literature on children's views about the nature of light. A complete account of this literature is presented in Chapter 3. The topic light was appropriate to pursue in part because of its great many conceptual challenges for students. In addition, from my own experience, I knew that light-related phenomena were a source of wonder and delight for children.

2.5 Pilot Interviews and Explorations: Talking With Children About Light

To begin the exploration of student ideas about the nature of light, two sets of interviews were conducted. The first set involved children in Division I (grades 1-3). The second set of interviews were conducted with students in a grade six class. My first question to all of the children interviewed was simply, "What is light?" Here, I used no referent or "prop" materials other than those already present in the room in which our interviews took place. I wanted to understand how children described and talked about light, and what prior experiences they had had with the light phenomena. This constituted the conversation with the division one students.

In the second set of interviews, with the grade six students, I provided activities involving numerous objects which produced intriguing light phenomena. These objects included:

a flashlight
a mirror and card with letters
transparent, translucent, and opaque objects
waterglasses and pencils
a glass prism
a "jupiterscope" (a 'space-age' jelly-like clear disc containing hundred of prisms)
two types of magnifiers
several moving object cards
a fiber optics flashlight

I asked the individual children interviewed to try several activities with me using one of the objects. Then I asked the children to describe what they had observed, and why the light behaved in the way that it did. Finally, I asked students to tell me how they knew that what they were saying about light was true.

I also used pictures and books to prompt discussion about understandings, previous experiences, and interest in light. I encouraged the children to share with me any experiences with light phenomena which they might have recalled previously or any interest relating to light phenomena which they might recall. Students frequently referred to toys which they played with which either reflected light or created some special light effect. Students reported other experiences with light, for example:

> D. refers to his electricity set as a reference when telling me how light functions.
>
> L. speaks about movies and television as the resource for her understanding of the function and purposes of lasers.
>
> I. asks me questions about the wires under the switchplate in her room which she recalls noticing when her father was changing the wiring in her room.
>
> B. and D. comment on the information which comes through other people in their world. B says, "I know about the colors in prisms, because my mother's boyfriend told me that." D. tells me that "my friend told me about what makes the rainbow in the water when I water the lawn with the hose."
>
> In a group interview, P., S., and L. use one another as sources of information during group discussion concerning the meanings of the various colors of light emitted from lasers in movies, and conjecture on the meaning of the colors.
>
> E. refers to a book which he once read as the source of his information regarding the inner workings of a light bulb.
>
> I. speaks about an activity with a teacher in a previous grade which she says proved to her that "light gives off heat."
>
> P. tells me that she figures things out on her own. She points out a connection among the materials that none of the other children have made. She concludes that the ribs on the plastic magnifier must act in some way like the ribs on the plastic card on which objects appear to be moving.

It was during these discussions that I became aware that the individual children with whom I was working were approaching the tasks which I presented to them in very special and different ways. Some examples from my notes follow:

Leon becomes very physically involved with the materials we are using. His responses to my questions are terse, to the point. He uses little language to respond to my queries, but uses abundant language to spontaneously describe the experience which he is having with the materials as he is working with them. He continually encourages me to become involved in the exploratory directions which he is taking.

Belinda appears very concerned that she give the correct answer to my queries. She wants to know the answers to my questions, but prefers not to speculate on them herself. She seems to want to be sure that she is right before she puts an idea forward. At one point, when I ask, "Why do you think that light is behaving that way?" she pauses and says, "I don't know. But I'll bet you do. Tell me, why does it behave that way?" She is reluctant to suggest her own reason why it does so. Yet frequently, during our conversation, Belinda uses simile to describe her observations. When we held a flashlight up to a translucent plastic surface, she looked at the reflection on the wall and spontaneously remarked, "That looks just like a spider's web!"

Penny began the investigations with a description of her own theory of light which included a description of positive particles which were always moving. In each subsequent task which I gave her, she made a conscious effort to provide an explanation which was consistent with her own original theory. When I asked her what the source of her theory was, she said that it was based partly upon her reading and partly upon her imagination. "I like to add my own ideas to what I learn about. It makes it more fun."

Observation of student approach to the materials and ideas became some of my most important findings in the initial stages of the research project. These approaches seemed key to understanding how students conceived of, anticipated, and reacted to the ideas and experiences which were presented to them as they were learning. Hence, understanding individual approaches to science learning became central to my interest.

As mentioned, these initial conversations were undertaken to help to clarify questions and the focus for the research study. I also hoped to determine the extent to which students would be able to share their interests in and previous experiences with science and the topic, light. Another purpose was to test out the effects of using audio- and videotaping equipment with the children. I was concerned that the children might feel inhibited or intimidated by such recording equipment. These initial studies provided the opportunity to assess student ease in front of the equipment to determine if it was an appropriate technology for recording and reflecting upon ideas. After an initial nervous self-conciousness, the children eventually seemed to ignore the presence of the camera, and spoke with me in a candid and relaxed manner.

2.6 Foreshadowings, Emerging Insights, and Continuing Reading During the Exploratory Studies

By this point, it was clear that one of the goals of the research project would be to understand children's ideas about light, and how these differed from the scientist's ideas about the nature of light. A second goal would be to determine the best ways that these ideas might be uncovered. I felt that this work was preliminary and basic to an understanding of how students related to the formal presentation of ideas in the classroom. The exploratory studies yielded some important observations central to the direction of the present project, and guided my readings and reflection on the project.

2.6.1 Foreshadowings and Emerging Insights

First, I found that, in general, the children who were interviewed and videotaped had very little understanding of current scientific ideas about the nature of light. Even those grade six students who had been involved in formal study of the topic less than a year prior to our interviews showed little or no understanding of the most basic and current scientific ideas about the nature of light. Students' explanations of light behavior in the examples which I showed them were often based upon spontaneous and commonsense reasoning. In most cases, these explanations for light phenomena were very different from currently accepted scientific explanations.

Another finding in the exploratory studies emerged when students were encouraged to pose their own questions about light. These questions focussed on topics typically found in their curriculum programs, but were of a real and current interest to the students interviewed. Some examples of the questions asked follow:

What is a black light? How does it work?

What's inside a light bulb, like the ones in the classroom?

How do you get the light from the sun to make an engine go?

What is a laser, exactly? Could I make one?
How does a firefly make light? Why does he do it?

How come it's better to wear white than black on a really hot day?

What makes my shoe laces glow in the dark?

But the individual approaches which students took as they explored ideas and materials were emerging as a crucial focus for the study. I found that each child demonstrated a very different approach to the tasks which I presented. In some instances, the approach was a very spontaneous, creative, and imaginative effort by the child to make sense of the problem posed. Some students seemed less willing to speculate on the nature of light or were reluctant to propose explanations or even ask questions about the topic. The general way that each child approached the phenomenon seemed to be reflected in the entire manner by which the individual became absorbed in, interested in, and attentive to the materials and ideas I presented. There also seemed to be a relationship between the approach taken in the tasks and the student's interest in knowing more about the subject. Even though each learner's ideas about natural phenomena seemed to be unique and personal, there were still similarities apparent in the elements of approaches to materials which were shared by others.

A final set of discoveries was made during the effort to encourage the children to externalize their ongoing thoughts as they considered some of the problems which I posed for them. This revealed that students held differing perceptions of their own abilities to "do science." These different conceptions of self as learner emerged through the ways that children spoke about their previous science experiences both in and outside of school. The latter sets of findings led me to an extensive investigation into the literature pertaining to student "learning styles" (see section 2.6.2). I was seeking to understand the significance of individual approaches to science learning I had observed in the tasks which I had given students.

2.6.2 Readings and Reflection During the Exploratory Phase

I sought greater understanding of the structure of personal, individual approaches to science learning which must be considered in addition to student ideas about phenomena. The topic light presents new and unusual ideas which are often nonsensical to many children, and so it was evident that this was a valuable focus for the exploration of some of the more pervasive problems experienced in the initiation of young children to science.

The "learning styles" literature, specificially the pioneering work of Gregorc (1979, 1983), provided an explanatory framework and theoretical constructs for categorizing learners' modes of perceiving and organizing information. Although this work offered some interesting explanations for students' individual approaches to learning, the study which I planned differed in that themes would emerge from the children themselves. I wanted to capture significant themes which depicted the personal orientations of the students themselves rather than impose pre-conceived categories upon the individuals in my study. This required a research approach which would allow such patterns to emerge over the six months which I planned to spend in the classroom. Personal Construct Theory, in its emphasis upon the uniqueness of each person's thought and action allowed the emergence of such themes. I intended, through the documentation of individual children's experience to provide greater understanding of the interplay between:

1. Ideas held by the children about the nature of light.
2. The presentation of the scientist's ideas by the teacher and the curriculum material.
3. The structure of the individuals' unique and personal approaches to learning during science lessons.

The examination of personal orientations to subject matter would emphasize the uniqueness and integrity of individuals whose approaches were being discussed rather than viewing and describing the children through pre-determined categories or stages. Reflection on Gareth Matthews' (1980, 1984) work re-emphasized the crucial argument that in an examination of children's philosophical development there is no progression through fixed, standard stages at different age levels as suggested by Piaget. Matthews suggests that one problem with Piaget's viewpoint is, for example:

> The unusual response is discounted as an unreliable indicator of the ways in which children think. The only valid criteria are based on multiplicity of results and on the comparison of individual reactions. [Piaget] But it is the deviant response that is most likely to be philosophically interesting. It seems most likely that the philosophically interesting comments a child makes will not so much express the child's settled convictions as explore a conceptual connection or make a conceptual joke.
> p. 39

Since my study would ask students about ideas which are essentially fundamental philosophic viewpoints about science, learning, and light, Matthews' comments seemed particularly appropriate. The normative studies of Piaget and his co-workers have given us some of the first and most detailed understandings into children's intuitive ideas about the physical world. The emphasis of his later work shifted to the assumption of the priority of logical-mathematical structures of knowledge and the age related stages of intellectual development which are based on the acquisition of these structures. "Physical knowledge," the understandings about the physical properties of objects, was distinguished from logical-mathematical knowledge which was considered to be a set of internalized systems of action. Though these two types of knowledge were distinguished, they were also considered to be interdependent developments. Much of the criticism of Piaget's later work is directed to its emphasis on context-free logical aspects of knowledge and stage development (Vygotsky, 1962; Novak, 1978; Brown and Desforges, 1979; Donaldson, 1978; Matthews, 1980, 1984).

Piaget made clear distinctions between children's spontaneous and nonspontaneous thought. The child's ideas of reality which are developed mainly through his own efforts were designated "spontaneous." "Nonspontaneous thought" was identified as that which resulted from direct influence by adults or others in the environment.

Vygotsky (1962) suggested that the sharp distinction which Piaget makes about these two types of thought contain errors in reasoning which weaken his argument both theoretically and in practical terms.

> Although he holds that the child, in forming a concept, stamps it with the characteristics of his own mentality, Piaget tends to apply this thesis only to spontaneous concepts and assumes that they alone can truly enlighten us on the special qualities of child thought; he fails to see the interaction between the two kinds of concepts and the bonds that unite them into a total system of concepts in the course of the child's development.
> p. 84

Vygotsky (1962) suggested that Piaget's concern that teachers have a thorough understanding of the child's spontaneous thought was guided by the underlying view that "child thought must be known as any enemy must be known in order to be fought successfully" (p. 85). Vygotsky cautioned that the implications of this thinking put seriously at risk the socialization of child thought. Vygotsky criticized Piaget's analysis. He argued that Piaget did not give attention to the child's own efforts and nature and gave the following account of Piaget's interpretation:

> Throughout childhood, there is a ceaseless conflict between the mutually antagonistic forms of thinking, with a series of compromises at each successive developmental level, until adult thought wins out. The child's own nature plays no constructive part in his intellectual progress.
>
> p. 85

In this case, Vygotsky was referring to the general nature of the child's efforts rather than idiosynchratic structures. In addition, the child/adult thought distinction, in this case, would be equivalent to the child's ideas about the nature of phenomena as contrasted with scientific explanations of the nature of phenomena. In a further support of Vygotsky's argument, Schmidt (1973) suggested caution in the contrast between spontaneous and nonspontaneous formation of ideas about natural phenomena. He pointed out that even in the spontaneous formation of a concept, "The child does not initiate the activity -- the activity is initiated in him by phenomena whose fascination he cannot escape" (p. 100). Likewise, in the situation where an adult-created environment holds the child's fascination, it is still the child's own interest in the phenomena which holds his or her attention. In Schmidt's view, the adult's use of words are given as an example of "leads that clearly imply that there is a great deal more to the phenomena, and that it is by turning to the phenomena themselves that one can discover more" (p. 101).

Vygotsky's critique epitomized the concerns which I was clarifying during the pilot phases of the development of the study, that a consideration of the preconceptions, misconceptions, or alternative conceptions of the child is incomplete if it does not consider and attempt to understand the child's personal encounter in the process of learning, or in Vygotsky's terms, how "the child's own nature" contributes to intellectual progress. I began to shape the study to understand the child's contribution in the encounter with natural phenomena, to convey the dynamic, changing nature of ideas, and the child's emotional response to the school's initiation to science learning. A study which documented and analyzed both the child's ideas about and approaches to phenomena in the school setting would contribute to our understanding of how students might best be helped to learn about, deal with, and interpret the scientists ideas about natural phenomena.

2.7 The Need for an Alternative Research Approach

As I became more familiar with the alternative framework research, I found that the great body of empirical studies acknowledge and delineate pre-formed ideas which children in the population as a whole tend to bring to their learning experiences. It seemed important and useful to develop an interactive study to complement this work which would provide and understanding of childrens' approaches to learning about natural phenomena in classrooms. This work would provide implications for the adult's role in guiding and directing the child's formal experience in school science, and would allow insight into the experiences of students who deviate from the general trend in the population.

The research approach of this study would be described by Driver and Easley (1978) as "ideographic" in that it seeks "to illuminate the way students understand phenomena" (p. 68). The study would employ what Power (1976) referred to as the "anthropological paradigm," in that it would be predominantly descriptive, using a participant observer methodology. Such studies do not attempt to predict student behavior, but in the tradition of ethnomethodology (Garfinkle, 1967, Cicourel, 1974, Wilson, 1977, Stake and Easley, 1978) seek to understand participants' viewpoints.

Wilson (1977) argued that the "social scientist cannot understand human behavior without understanding the framework within which the subjects interpret their thoughts, feelings and actions" (p. 249). The project was guided by this thinking, and I planned to conduct the study in the "naturalistic setting" of a grade five classroom.

2.8 Case Study: The Perception of Unity- Development of the Case Study Reports

Louis Smith (1978) describes the key notion in the study of the individual case to be that "you have some kind of entity, a case, and that it has some kind of unity. Someone perceives a part of that unity and wants to study some more of it." In preliminary investigations and pilot work I noted patterns and themes in the ways that individuals were approaching the study of natural phenomena in schools which I had not found described in the literature. I believed that the case study approach would allow a telling of the story of each child's experience of school science learning.

Smith (1978) refers to the case study as "the story of a bounded system in its own habitat."

> The case study tells a story about a bounded system. It has character, it has a totality, it has boundaries. It is not something we want to represent by a score or an array of scores. It is a complex, dynamic system. We want to understand its complexity.
>
> p. 23

The case study approach has long been known as the research procedure of anthropologists and other behavioral scientists, but it does not have a long history in the field of education (Eisner, 1981). Goode and Hat (1976) described the case study "not as a specific technique, but as a way of organizing social data so as to preserve the unitary character of the social object being studied" (page 114). I planned to use several techniques to clarify and preserve the unitary character of each child's story. Information for the study would be gathered through formal and informal conversation, through the use of Repertory Grid conversations, through videotape and audiotape recordings, through the collection and discussion of student work, notes, stories, drawings, and written reports, and through my own participation and observation in the classroom.

2.9 The Uses of Case Study Reports

Easley (1982) advocated the use of case studies to help teachers understand difficulties which students were having in learning which seemed to overwhelm them. Both in and outside of the school he noted that teachers were making such comments as "Everything is going well, except that I have one boy who doesn't seem able to attend to the subject. He doesn't know how to study" (p. 193). Easley's case study approach allowed him to discover a pattern in the difficulties which the student was having:

> ...in almost all cases, we find an explanation for why the student is failing to achieve in school. For example, it may be that the child is enamored with some ideas which are, on the surface, not acceptable to the teacher. We also find educational projects which the child could undertake, if the necessary support for it were available.
>
> p. 194

It was clear that the case study approach could add significantly to our understanding of the complex of features involved in the young child's experience of school science learning. I planned a series of case studies to be based upon the perspectives of several very different children in a classroom. I hoped to acquaint readers with the experiences and approaches of a variety of children in a grade five class during their learning about the specific topic, light.

The patterns or unities which I would then perceive would be grounded in direct experience and long term involvement with the children in the class. Description and analysis during the first period of observation would be based upon Glaser and Strauss's (1967) elaboration of the discovery of grounded theory. In this approach, after a period of preliminary observation, the collection of data and the analysis of data take place simultaneously. Categories or theoretical constructs which emerge and which appeared to inform the study could be tested with individuals and, in this situation, with their ongoing experiences. As the observations become noteworthy, themes would emerge for each child and could be compared with previously emerging themes. In this way, I would be able to compare my findings with those reported in the "alternative frameworks literature." I would be able to able to look not only at the influence of children's prior ideas about the nature of light, but at how students' approaches to the study of a particular topic in science affected the development of ideas, attention in class, and students' views of themselves as science learners. My next step was to throughly examine the literature on the selected science topic and the research approaches which had been used in studies of children learning science.

Chapter 3

STUDIES OF CHILDREN LEARNING SCIENCE

3.1 Introduction

A review of recent literature on children's science learning finds the study of the child's viewpoint currently at the forefront of interest in science education research. This vast body of literature not only examines many different content areas in science, but researchers employ a variety of approaches to understanding the experience of children's learning. A review of the literature is organized in this chapter as follows: Section 3.2, "The Alternative Frameworks Literature" provides a general overview of terminologies, and research paradigms in studies which have been conducted. Section 3.3, "Children's Ideas About the Nature of Light," reviews the findings and orientations of research studies which have attempted to describe student ideas about the nature of light. There are two main thrusts evident in the latter body of work: 1) Studies which focus upon pervasive misconceptions, and 2) Studies which emphasize the child's interpretive framework. The impact of the alternative frameworks research on educational practice and the need for alternative research approaches are discussed at the end of this chapter.

3.2 The Alternative Frameworks Literature

The recent "alternative frameworks" emphasis in science education literature seeks an understanding of students' views regarding the nature of phenomena. This large, growing, and almost overflowing body of research, gives attention both to students' understandings of the nature of specific natural phenomena, and to the methods and approaches which best uncover these views. In some studies, ideas held prior to instruction are the focus. In others, student errors in thinking or deviations from scientific explanations are considered significant, while in still others, post-instructional content knowledge or retention has been of interest.

Piaget (1929, 1974) was one of the first researchers who systematically studied children's ideas about the nature of the world. Current studies often build upon the principles and outcomes of his original work and that of his coresearchers. However, just as Piaget's work has come under recent scrutiny and is subject to a variety of interpretations, a wide variety of opinions exists concerning the value, purposes, goals, and eventual uses of the great number of these alternative framework research studies. Therefore it is not surprising that there exists a great divergence of views regarding the appropriate and most useful terminology in these studies, and the methodological approaches which best explain and guide the various research projects.

3.2.1 Examining the Research on Students' Alternative Frameworks

The attention which alternative frameworks research in science education has received in recent years was notable at the International Seminar on Misconceptions in Science and Mathematics at Cornell University, June 20-22, 1983. Although organized with no outside funding, over fifty-five papers from international scholars were presented (Helm and Novak, 1983). The primary purpose of the conference was to promote dialogue among scholars concerned with the "highly robust" (Posner, et al. 1982) influence which students' prior conceptual frameworks have upon shaping the meaning of new learning (Helm and Novak, 1983). Other conferences have been held on a smaller scale, for example, the predecessor to the Cornell Conference, the research seminar, Investigating Childrens' Existing Ideas About Science (Sutton and West, 1982). This symposium also brought an internationally known group of scholars together in a fruitful exchange of papers, problems, findings, approaches, and theoretical orientations to the research.

An examination of the literature shows that many different conceptual approaches 'drive' the various projects. Gilbert and Watts (1983) note that the pace of research in content and context dependent science has rapidly increased since the early 1970's. Yet, despite so much activity in this area, there has been little agreement upon the aims of the inquiries, or upon the terminologies to be used in discussing student views. Several researchers indicate a preference not to use the specific term, misconception, for example, (Wheeler, 1983; Gilbert and Pope, 1982) because of the assumption in the use of the term that the students' process of understanding is less important than the endpoint of his or her learning. Most of the research in alternative frameworks has attempted to determine the patterns of ideas which students hold and to which they cling even after instruction. But documentation of the processes by which many other factors interweave to affect the individual child's creation of meaning and interpretation of science learning has not yet been adequately conveyed.

Some researchers ask, "What are the barriers to science learning?" (Appelman, et al. 1979; Ault, 1980). Those with a concern for understanding the child's interpretive framework would ask the question differently: "In what ways do the childrens' past experiences, understandings, and expectations affect their learning of science?" A subtle difference exists between the two questions. The former question seeks to define the hindrances to learning science. The "solution" for these researchers would lie, then, in discovering how educators might direct their energies to 'break down' these barriers. In contrast, the interpretive framework orientation sees the students' present knowledge not always as barrier to understanding, but as a framework leading to an opportunity for students to re-interpret information (West, 1982, pp. 38-39). The "solution" in the interpretive framework view is in discovering the direction of student thought concerning a problem. The assumption of this view is that if educators acknowledge the value of the students' interpretive framework, then it will be seen that though the student does not yet understand an idea or is simply "wrong," about it, she or he may be "intelligently wrong" (Ault, 1984). The solution in this approach is to understand the ways that the child is thinking about the problem, to value the child's thought, and to help the child become aware of the development of his or her own ideas.

3.2.2 Current Studies: Terminology

Studies have been conducted dealing with a variety of topics, including paths of acceleration (Viennot, 1979) to energy (Wheeler, 1983), dynamics (Osborne, 1980), geologic time, (Ault, 1980), growth (Schaefer, 1979), and many others. Numerous terms have been used to describe student ideas about these topics. For example, ideas formed prior to instruction have been termed prior knowledge (Wittrock, 1974). Incorrectly formed ideas have been referred to as misconceptions, and ideas which may diverge less drastically from "scientifically correct" explanations of natural phenomena have been called alternative conceptions.

Childrens' views about the nature of phenomena have also been variously labelled using such terms as ideas (Osborne, 1981), beliefs (Karbo, Hobbs and Erickson, 1980), understandings (Nussbaum and Novik, 1976), preconceptions (Anderson and Smith, 1983), viewpoints (Erickson, 1980), prior knowledge (Sutton, 1980), alternate conceptions (Minstrel, 1983), conceptual ecologies (Posner and Strike, 1982), conceptual frameworks, (Driver, 1973), cosmographies (Sneider, C. and Pulos, S., 1983), mixed conceptions (Ault, 1984), personal constructs (Kelly, 1962), gut science (Claxton, 1982), and children's science (Gilbert and Watts, 1982, Zylbersztajn, 1982).

3.2.3 Current Studies: Research Paradigms

It has been clearly established in numerous studies (Driver and Oldham, 1985, Osborne and Freyberg 1985, Fensham, 1983 and Driver and Erickson, 1983) that children embark on the study of natural phenomena with ideas already formed through their own backgrounds and experience. It is clear that children's ideas about phenomena grow and change as they are taught science in school settings, though not always in ways that are intended by teachers, curriculum makers, or even by curriculum makers who are aware of the research findings. It is also clear that studies are guided by one of two basic research philosophies which determine the ways that information is collected and ultimately used. The first philosophy seeks to determine childrens' specific ideas which are in conflict with the scientific presentation of ideas in the classroom. Driver and Easley (1978) call these studies "nomothetic." Students' understandings are assessed in nomothetic studies in terms of the congruence of their responses with 'accepted' scientific ideas. As described previously, suggestions are then made concerning ways to "extinguish" incorrect ideas, and bring students to the correct responses on post-tests (Anderson and Smith, 1983). The second major research thrust emphasizes the interaction of student ideas with those presented by the teacher or curriculum materials in the science classroom. The child's ideas are used as an interpretive framework. This framework is used to gain an understanding of how the student is thinking about the phenomena and how these ideas affect the development of new ideas. Driver and Easley (1978) refer to these studies as "ideographic." Ideographic studies, referred to by Parlett (1977) as illuminative, illuminating the ways pupils understand phenomena. These studies employ a methodology described by Power (1976) as "the anthropological paradigm."

Taking an ideographic approach, Brook, et al (1984) examined student ideas about the particulate nature of matter and showed how some incorrect answers occurred because students apparently completely misunderstood the questions which were given on a written test on subject matter. Some of these students responded at completely different conceptual levels during interviews than those which they demonstrated on written tests. It is clear that the methods used to assess student understanding greatly affect our findings.

In another set of studies using an ideographic approach, Solomon, (1981, 1983) showed how children's knowledge of the everyday meanings of terms such as 'work' or 'force' may be one reason why students have difficulty understanding and using scientific definitions of the same terms during science class. She suggests that children are asked to operate in two different knowledge domains as they learn in school, the domain of their own lived experience and the domain of knowledge generated by science. The confusion of switching from one domain to the other makes the experience of learning difficult, as the student is unsure of the boundaries of the knowledge domains or when words have one meaning and when another. These examples of illuminative approaches to studying science learning seek understanding of student ideas as interpretive frameworks not for the purpose of "extinguishing" wrong ideas, but for the purpose of understanding the many interrelating factors which affect the student's total experience. Such approaches seek to understand rather than to brush aside the students' difficulties, accepting the need which Whitman expresses in his poem rather than dismissing it as weakness, as Asimov suggests we do.

3.3 Studies of Children Learning About Science Phenomena

The purpose of the present study was to document how children's individual approaches to science learning interact with science study. Very few studies have been undertaken to gain an insight into the ongoing nature of the child's experience of learning about science. Some older, now classical studies (Piaget, 1979; Isaacs, 1930; Navarra, 1955) are concerned generally with the development of student ideas. These have provided starting points for pilot work and have demonstrated the relative merits of a variety of research approaches.

3.4 Selection of the Topic, Light

Light was the topic selected for study for several reasons. Very little research had been undertaken to directly address the question of students' ideas about the nature of light: Guesne, 1978; Stead and Osborne, 1979, 1980a, 1980b; Jung, 1981; and Andersson and Karrqvist, 1982. The sparsity of studies is surprising as the topic is so pervasive, not only in the science curriculum, but in the everyday life of students.

3.4.1 Light in the Science Curriculum

The topic, light, is frequently dealt with early in the elementary school curriculum in Alberta. 'Light and Shadow' is a topic commonly studied in grade two. The mechanism of vision is often presented in the grade four program. A study dealing specifically with the nature of light often takes place at the grade five level. In the secondary school physics program, the topic "light" is a topic of even greater prominance.

Despite this fairly extensive emphasis on the topic throughout years of school science learning, scientists' ideas about the nature of light have traditionally been very difficult for students to grasp. This finding was corroborated in the pilot studies for the present project discussed in Chapter 2.

3.4.2 Light in the Everyday Lives of Students

Light phenomena hold an enormous fascination for children. Shadows become inseparable playmates in childhood. The wonder of rainbow formation in the sky after a rain or when seen through a prisms, totally captivates the observer. Children are enthralled by the colors of the sunset, by the images they see through magnifying lenses, by the twinkling of stars, by many effects of light behavior. We have all delighted in the possibilities of shadow and light play with flashlights, gasping at the image of red blood seen through the thin skin of hands over light beams.

Through humankind's recent ventures into outer space, children have come to consider Spacecamp and flights to the moon as very probable experiences in their futures. Children consider the universe as a frontier for scientists and for themselves. Light travel and laser technology are topics of everyday conversation. These phenomena can be understood more fully through a grasp of some of the basic principles of light behavior. An aesthetic appreciation of the variety of light phenomena and children's experiences with light has been found in the present study to be an important factor in the establishment and persistence of student interest and enjoyment in the ongoing study of natural phenomena. In the daily lives of children, knowledge about the nature of light allows understanding of a wide range of phenomena which explains events and empower the individual in everyday situations. For example, explaining such events as the prediction of the behavior of light when reflected by a mirror, the consideration of reflected light in photography, in the understanding of the basic mechanism of vision, of simple lens systems such as eyeglasses, microscopes, and telescopes. Knowledge of light phenomena allows us to answer questions which arise along with the wonder experienced at the sight of rainbows, of color reflected through prisms, celestial light phenomena and other reflecting and refracting systems. Because of the importance of understanding light, and yet the difficulties present in its study, several researchers have undertaken to grasp student ideas about the nature of light. Two main main thrusts of research emphasis can be seen in studies of light. These are used to group the studies which are described in the following sections.

3.5 Emphasis I: Studies Which Focus Upon Pervasive Misconceptions

Piaget (1974) devoted study to children's ideas of causality in operations with specific phenomena. He noted certain "lags" in students' general understandings of ideas regarding the transmission of heat. He then turned to light to add further to his understanding of childrens' ideas of causality. In almost every individual questioned about the nature of an image in a mirror, or the light cast by a lamp, Piaget noted the understanding of vision as a passage from the eye to the object, rather than the reverse (p. 103). When a flashlight is shone in the dark, there is acknowledgement by some individuals that the light is shining on the eye, but most continue to describe the direction of vision as passing from eye to object.

When a light is shone on a screen located at varying distances from the person, no idea of light transmission or travelling is mentioned up to Piaget's level IIB, but some type of "action" is described as taking place at a distance. When this distance is changed and the size of the circles of light are seen to increase and decrease, children in level IB suggest that the larger circle is obviously being created by a greater amount of light, yet the majority claim that there is nothing between the light sources and the screen. In Piaget's level IIA, this same point is made by children, though at this stage students appear to sense a contradiction. Piaget states, however, that the child does not verbalize this contradiction. At level IIB, the individual begins to make statements such as, the light "leaves" or "comes straight forward." Piaget then hypothesized, basing his idea upon studies of childrens' ideas about both heat and light, that the "attribution of the operations of the objects, therefore the success of causal explanations, especially in the field of transmissions, is a function of the causal action of the active controls or material regulations that ensure their success" (p. 105). The cause of light, therefore, is attributed to the fact of its *being turned on*, for example, by using a light switch, and ideas about the transmission of light are not understood.

Guesne (1978, 1985) conducted interviews on the nature of light and vision with twenty fourteen year old students. Given an object, the students were first asked, "What is it that makes you see this object?" They were then encouraged to explain how both primary and secondary sources of light are seen. Guesne reports that most of the students expressed the belief that objects are seen *because they are bright or because light falls on them*, but that most of the students interviewed do not mention that the eye detects light reflected from an object. Most of the students report that objects are seen by the action of looking at them, that is, that vision can be traced in a direction from human eye to the object. Guesne argues that our everyday language concerning vision tends to give support to this view, and that it is very similar to the views of Platonic and Pythagorean theories which assumed that vision could be best described as a ray emanating from the eye of the subject to the object seen.

Stead and Osborne (1980) used an "interview-about-instances" procedure based on the work of Gilbert, Watts and Osborne (1981) to obtain records of the ideas students between ages nine and sixteen hold about light. Three main aspects of the nature of light were delineated for study: 1) transmission of light, 2) sources and reflectors of light, and 3) vision. The results of two different approaches to data collection were compared in this study. The first used the structured interview-about-instances method. Students were shown a set of pictures depicting light phenomena and were asked to make statements about light behavior in the pictures. Thirty-six students were first interviewed. None of these students had studied the topic light within the previous 12 months.

The second approach was the provision of a multiple choice test, which had undergone several revisions before its administration to 235 New Zealand students who had recently studied light. The test results showed that students who had received recent instruction on the topic held views which were very similar to those who had received no instruction. The authors conceded that a weakness of the findings in the multiple choice test was that students' reasons for selecting a particular answer on such a test cannot be known with any certainty. However, there were some important generalizations which could be made about student ideas in the study:

> ...both the qualitative and quantitative method produced evidence that many students of different ages, and with different amounts of formal tuition did not see light as travelling far from a source or reflector during the day. Most students saw light as travelling further at night. Few students had a concept of light travelling that matched the scientific concept and that was constant over all ten instances.
>
> p. 90

There was little difference between the ideas of Form 3 students, who had received formal instruction on the topic, and Form 2 students, who had received no instruction on the topic. The authors concluded that the reason that teaching appeared to be unsuccessful in moving students to the scientific conception was that no teaching was deliberately directed to the confront the 'erroneous' ideas that students held.

Similar points are made in a study of Swedish students, aged 12-15, published by Andersson and Karrqvist (1982, 1983). In this study only a few of the students interviewed indicated that they understood the nature of light as 'a physical entity' existing in space and separate from its source and effects, the scientist's viewpoint.

3.6 Emphasis II: The Child's Interpretive Framework

Several early studies explore the process of the development of scientific concepts in children. In some of these projects, embryonic ideas are presented which have directed future work. One example is the emphasis upon childrens' questions, as found in the appendix of Susan Isaacs' study (1930) Intellectual Growth in Young Children. The appendix, "Childrens' Why Questions," offers insight into the ways that children puzzle over events and phenomena in their environment. Such an approach informs us of the types of questions the young child thinks are important and reasonable to ask about the world. For example, one four year old asks, before going to bed, "Why does it get lighter outside when you put the light out?" In a commentary on the questions Nathan Isaacs (1974) stresses the importance of considering the child's question, not with an emphasis on the incorrect idea in the question, but as a resource for understanding the child's ideas about the phenomenon and of his or her way of coming to grips with what perplexes him.

For to the child it appears as though it has become lighter outside. It is perhaps less an "error" in thinking than it is that the child focusses upon himself as the central and only observer in the situation.

Isaacs (1974) suggested that understanding the way that the child learns is a framework through which the child meets and interprets the world.

> And thus we get to the crux of the matter. Puzzlement is a state of disorientation and at-a-lossness. To understand it, we must understand the previous state of orientation and implicit confidence. The simple key is that even children down to three to four years have already built up within their minds a quite far-reaching working model of their world, a sort of proto-science of the kinds and constancies of things and the regular rules of their behavior and relations. This guides them in all their ways about their world, enables them to recognize the objects and happenings they meet, and thus permits them to foresee what to expect and how to respond and plan to act. But periodically, something goes wrong: their proto-science is, after all, still very imperfect and in particular very untested. They are too apt suddenly to find themselves hurt because some assumption or belief, implict or explicit, has collapsed on them. They then pick up the why question in our present sense as the recognized way of expressing their at-a-loss state and invoking the adult's help in coping with it.

Navarra's study (1951) of a preschool child, his own son, spanned a period of two years. He also believed that it was important to look beyond the child's "incorrect" ideas, to the ways that the child is considering a problem. An example is given through his records of a conversation with the four year old subject of the study, L.B. The light from the moon is being discussed:

> L.B., his mother, and his father were taking a walk. Mother casually remarked as she pointed toward the moon, "Only half the moon is lit. Isn't it pretty?" L.B. very seriously interjected, "Would it burn your hands?" His question was not answered directly. Rather, his mother prompted, "What do you mean--would it burn your hands?" L.B. wrinkled his brow as he thoughtfully replied, "If it's lit up, it could burn your hands."
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> p. 99

Navarra points out how the child's immediate and direct experience with moonlight are limited. He cannot touch and handle the moon. The information which was supplied by his mother did contain some meaning in terms of L.B's experience. He had seen and touched lightbulbs which were hot enough to "burn your hands," and so was making a logical deduction on the basis of this past experience. This experience was a reference point for the integration and organization of further information pertaining to the moon. "Thus an erroneous assumption within L.B.'s experience became a potentially useful guide in his conceptual development" (p. 99). Navarra states that the most significant inference from the records of his study was the persistent growth and refinement of L.B.'s experience. The child's understanding appeared to derive from a procedure which was directional and systematic. The process whereby L.B. coped with his dilemmas grew out of his interaction with the environment. The understanding of this process was possible because of the long term nature of the research project which enabled Navarra to consider L.B. as a whole person, seeing how both ideas and emotions affected the development of concepts.

Jung (1981) studied children aged 12-15 years of age, and suggested that ideas about light could be understood through "meaning frames" of perception as well as of cognition. As an example, he gives the "common sense frame" of seeing light and color. Following the philosophical argument which describes perception as a phenomenon, he noted that "that which is perceived is given itself, as something which exists in its own right, irrespective of the fact of being perceived." Thus color is seen as something which the object possesses as a real quality. What we do not see is light itself. It is regarded primarily as the condition for seeing. Light is not commonly known as the mechanism by which the actual color of an object arrives to our eyes.

And because light is not recognized as the mechanism by which we see, but in different ways, sometimes as a radiation or streaming of colors, sometimes as brightness, there is a confusion of perceptual and cognitive frames. Jung suggests that the teaching solution is not a matter of simply showing students the right way of viewing as opposed to the incorrect one, but is a matter of showing students the differences in context which makes one "meaning frame" more appropriate than another.

In Jung's first example, students who had been given instruction in elementary optics were asked to observe a distant light source through a double slit, and to report what they saw. They were then to explain how they saw it. Jung expected that some of the students might explain the phenomenon in terms of the "physical meaning frame" in which they had been taught, but found that more than half of the students explained what they had seen in a common sense meaning frame, that is, that "they saw the [light] source radiating sideways." This may not be the best example of what Jung hoped to demonstrate, as asking students to describe what they see is not the same as asking them to apply a concept which they have learned. However, it does clearly demonstrate his original point, that people are reluctant to doubt that what they perceive to exist does, in fact, exist.

In a second investigation, twelve year old boys and girls, when given a mirror, stated, in 90% of cases, that they saw their images on the surface of the mirror, as opposed to what Jung calls "from behind" the mirror. The students comment that 'light is reflected from the surface of the mirror, so that is the place where the image is formed.' In this study, no student gave an adequate explanation by drawing upon the prior instruction in ray reflection, a topic which they had been taught extensively.

In another example, students said that a light beam directed onto a mirror in a darkened room could be seen both reflected from the mirror and on the mirror because it was acutally lying on the surface of the mirror.

The study leaves some very intriguing questions. For example, why did some of the students apply what they had learned in class, while others returned to a "common sense" meaning frame when asked to comment on a new example? Does this mean that those who returned to the "common sense" meaning frame did not grasp the "physical frame," which the author equates with the correct scientific explanation? What would encourage students to "switch" from the common sense meaning frame to the physical frame?

The only study found which explored the ongoing development of ideas during instruction was that of Appleman et al. (1982), A Report of Research on Critical Barriers to the Learning and Understanding of Elementary Science. This National Science Foundation Project culminated two years of research on the experiences of elementary school teachers who were learning about science topics in which they had had little or no previous instruction. The teachers attended classes at a local university evenings to learn more about selected science topics. The authors of the project sought to understand the difficulties which are experienced in the study of science and mathematics, and to begin to develop what they refer to as a "pre-theoretical" set of categories describing these difficulties. The project was committed to the philosophy that an "essential phase of the teacher's art must be conceived of as supporting and seeking to guide the learner's own reconstructive commitments and efforts in learning." Where shifts in these commitments were needed, the authors suggest that a teaching style which simply transmits more scientific information, more knowledge, into the learner's already established approach may prove radically inefficient, even producing more harm in some cases than good. In the authors' term, this may result in a "pedagogenic" practice (Part C, page 18), an analogy to disease contracted by patients which is actually induced by physicians who are attempting to cure them of something else.

Appleman et al. (1982) call the pre-theoretical categories which are presented in the study "barrier phenomena," that is, phenomena which apparently inhibit learning. The ethnographic character of the study allowed the authors to describe these phenomena in the ecological contexts of learning events. An effort was made also to seek clues from the history of science to understand the intellectual origins of "barrier phenomena". Examples of barriers include:

1. Pervasive Barriers: Problems with scientific reasoning; confusing two concepts that apply to the same situation; confusing reality with its representations; making inappropriate associations; retrieving malinformation.

2. Barriers Recognized in Narrower Contexts: Invisibles and impalpables; conservation laws: transformations and cycles; wholes and their parts; constructs and their measures, scale and relativity.

The authors state that their interest is in stimulating conjecture on the nature and origins of the difficulties which learners experience. Light was one of the topics selected for study in the research project because of the numerous conceptual difficulties associated with learning about light and light related topics. In a beginning activity, for example, participants were given colored theatrical gels to use in mixing light. Discussions among participants showed the tendency to conceive of color as a property of the physical surface of an object, not as relative to illumination or perception of the object.

The authors also found that patterns emerged explaining some of the dilemmas which students encounter when studying light. Two distinct conceptions of light, not clearly related to each other, are thought to be in operation. In the first, students consider light to be "the essential condition of vision, the opposite of darkness." It is simply described as the opposite of the static condition of darkness. The other contrasting conception of light is that of an entity which emanates from a source like the sun or a lightbulb. The authors found that they had presupposed understanding of the central idea of geometrical optics, the abstract physical-geometrical notion of the light ray as something which travels, a concept which in fact is not understood by elementary school teachers.

Other published research reports repeat and support the points which have been made in Appleman et al.'s (1983) ground-breaking study. La Rosa et al. (1984) reiterate the distinction between the ideas inherent in the ancient terms, 'lux' and 'lumen' making an argument similar to that previously stated by Guesne (1978, 1985), Appleman et al. (1983) and Andersson and Karrqvist (1982, 1983). This argument states that everyday meanings of terms are quite different when used in the science learning context, and that this may be a source of confusion to the learner.

3.7 The Impact of Alternative Frameworks Research on Educational Practice

Fensham (1983) suggests that two main aspects of the findings of alternative frameworks research have begun to create an impact upon curriculum development and classroom practice.

1. The studies indicate that teachers may not have been previously aware that students bring to the classroom their own conceptual structure for organizing and understanding the world.

2. Researchers have found that even after instructional sequences designed to change this conceptual structure, children will often hold to their previous understanding given a different context for the problem. This occurs even after instruction has shown their original ideas to be incorrect.

In an interpretation of the potential for practical application of these findings, Minstrel (1983) states that this research points to significant tactical errors which teachers may be making in science teaching that do not take students' conceptual orientation into account:

> Perhaps in teaching we do not address the ideas our students bring to science class. We often try to superimpose new information onto a student's way of organizing the world. The student is then left to memorize principles, laws, and equations as if they were a new language. Science class becomes a foreign culture, rather than a place to discuss, to investigate, and to organize the phenomena of the world.
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> p. 53

Fensham (1983) points to this body of research as having a strong and important impact upon the framework of thought, practice, and research in science education.

> ...a number of hitherto disparate research groups have converged on a clinical methodology to elucidate the learner's basis (or prior understanding) for his/her statements and actions about science topics. Thus we find Easley and Driver (1978), Neo-Piagetians, White (1979), a Gagnean, and Novak (1978), an Ausubelian, to be very close in their current activities and interests.
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> p. 5

But once several of the basic and most pervasive alternative orientations towards phenomena are identified, the next logical step may not be only to ask, "What can we do differently in classrooms to prevent, extinguish, or fix these wrong ideas?." Phrasing the problem in this manner suggests that we can already clearly identify and understand the mechanisms by which children come to be right or wrong about an idea. Such a question focusses upon the beginning (entry) and the endpoint (exit) of learning rather than upon the processes of learning in the classroom. If we focus our attention only upon the entering and exiting points, without developing an understanding of the processes by which children come to understand, we may fail in our attempts to assist children in making conceptual shifts, leaps, and reorientations.

Fensham (1983) notes that a second set of studies has investigated deficiencies in the underlying knowledge of science concepts by students who have been previously regarded as relatively successful achievers in overall academic performance. These students become superior achievers in science despite their lack of understanding of concepts. Clearly, success has been achieved without a grasp of ideas. There have been very few studies designed to understand the complexities of the personal experiences of learning science.

3.8 The Need for Alternative Research Approaches

The research paradigm of the majority of studies in the alternative frameworks literature has been based upon the assumptions and procedures of a clinical interview methodology. Information is gathered which does not take into account information concerning childrens' learning processes and interaction in the classroom. In most studies, an attempt has been made to generalize regarding the normative pattern of ideas, or the trend occurring in the population. Many of the studies have sought to identify specific and pervasive "misconceptions" which students hold, then suggest ways to correct these "wrong" ideas. Power (1976) notes that the underlying assumption of this approach is that of the "scientific paradigm," that generalizations across populations, classrooms, and classroom phenomena are both possible and useful (p. 18). While this approach has provided us with some important details of certain aspects of student understanding, little information has been provided about the physical, social, and temporal contexts within which events occur and which help to give them meaning. We have not been provided with insight and understanding into the interpretations of classroom events by participants. What is needed is insight into the gestalt of interacting environmental, social, and cognitive factors which should be a part of our account of childrens' experience of science learning.

Chapter 4

TOWARDS LISTENING DIFFERENTLY: PHILOSOPHICAL COMMITMENTS CENTRAL TO THE RESEARCH STANCE

4.1 Philosophical Commitments of the "Alternative Frameworks Research"

In the enormous and growing literature concerning student understandings in science, we find studies based upon a wide variety of philosophical positions regarding the nature of learning processes and the nature of knowledge in science. Researchers' metaphysical/philosophical commitments which underlie these positions are often implied rather than explicitly stated in many of these studies. A lack of clarity of the researcher's orientation may confound the reader's interpretation of a study. A clear understanding of the researcher's philosophical stance allows the reader to comprehend how philosophical commitments have affected the collection and interpretation of data and subsequently the knowledge and value claims of a study. As an example, one well-known orientation to educational research produces studies which explain the success or failure of children in classrooms in terms of amount of "time spent on task" (Rosenshine, 1979, Fischer, et al, 1980). This work places time in a position of paramount importance. As Lakoff and Johnson (1980) observe, this view is committed to and "lives" the metaphor "time is money." Time is considered a "valuable commodity," something "not to be wasted." The value claims of such a research project build upon a conception of human nature as essentially a set of behaviors which must be externally manipulated or controlled in order for the learner to be successful.

Another researcher working with the same philosophical foundation may apply a different theory, for example, one which explains student success or failure in terms of teacher reinforcement of correct responses during learning sessions (e.g., Skinner, 1968). This view also is based upon a fundamental conception of human nature as essentially a set of behaviors which must be manipulated and controlled in order for learning to be successful. The metaphor underlying this orientation is "person the machine" which calls upon the familiar mechanistic explanation of human behavior.

The knowledge and value claims of research projects are rarely presented in terms of the "world view" or philosophical and metaphysical commitments and assumptions of those presenting data (Novak and Gowin, 1984). When these commitments and assumptions are made clear to the reader, he or she is able to consider the data presented in terms of the conceptual underpinnings which have guided the work. The reader is then able to review and evaluate the research findings more critically.

4.2 A Constructivist Explanation of Human Behavior

The present study is based upon the philosophical views embodied in the constructivist research stance. Several very different theories are considered to be constructivist in orientation. In all of these approaches, human beings are seen as defining their own situations and indicating to themselves the meaning of the circumstance in which they find themselves. The basic view of the constructivist position for classroom learning is that the learner actively participates in his or her own construction of meaning. The constructivist position asserts that participants' views of their own reality are essential in building an understanding of the process by which reality is constructed by participants. One example is symbolic interaction theory, first developed by Mead (1934), which assumes that the actor in a given situation interprets or acts on the basis of symbols to which he or she gives meanings. In symbolic interaction theory, the individual's meanings are related to the ongoing activity of the person's social world. Another example is Vygotsky's (1962) theory of thought and language which asserts that it is "inner speech," or what one says to oneself in a given situation, which guides behavior. In a recent application of Vygotsky's work (Rohrkemper, 1984), the nature and content of inner speech was sought and was found to be related to achievement in problem solving in mathematics. Piaget's theory of cognitive development and Ausubel's theory of meaningful learning are also considered to be constructivist theories.

In his analysis of numerous studies which have been based on constructivist theories of learning, Swift (1984) argues that it may be more valuable to consider a number of subdivisions within the the constructivist tradition. Swift analyzed differences in constructivist stances taken by researchers in terms of the degree of the individual's _active participation_ in knowledge construction. In Swift's analysis, the epistemology of Piaget occupies a conservative position on a proposed conservative-activist classification continuum. Constructivist researchers who place great importance on the individual's active participation in the construction of knowledge are placed on the more active end of the continuum. As contrasted with Piaget, Swift considered George Kelly's work to be radically activist in orientation.

The prolific educational writer, John Dewey (1913), also might be considered to take an active constructivist orientation. Dewey's theory of interest and effort in education was based upon the following single principle:

> The genuine principle of interest is the principle of the recognized identity of the fact to be learned or the action proposed with the growing self; that it lies in the direction of the agent's own growth, and

> is, therefore, imperiously demanded, if the agent is to be himself. Let this condition of identification once be secured, and we have neither to appeal to sheer strength of will, nor to occupy ourselves with making things interesting.
>
> p. 7

Dewey believed that the essential quality needed for growth and development in education was that the student find personal meaning in his or her own studies. He contended that our efforts as educators should not be wasted on attempts to motivate pupils to achieve personal and cognitive clarity from without. He believed that because students seek understanding *before* they enter classrooms, that it is more important that educators spend time attempting to understand the meanings which events hold for students. Dewey's emphasis on the construction of meaning from within the person, is contrasted with a position which sees reality as a stable arrangement of subdivisions of objective facts, which the educator must implant in the passive pupil. Though the constructivist position emphasizes the creation of meaning about reality, two levels of meaning are possible. One position emphasizes the idiosyncratic nature of each learner's perception, viewing reality as a personally negotiated experience (Pope and Gilbert, 1982). The second position emphasizes a socially constructed reality which stresses meanings which are attributed by social groups (Berger and

Luckman, 1966). The present work is concerned with the personal construction of reality in the classroom setting.

4.3 Constructivist Approaches In Educational Research

The fundamental assumption of the constructivist orientation in educational research is that the learner's perspective is a valid and important source of information to inform and guide teaching and learning. The procedures for data gathering are also based upon this foundation. The work is rooted in the basic assumption that human beings are essentially striving for personal growth and well-being. The locus of control of behavior resides basically within the control of the individual (Kelly, 1955; Dewey, 1913; Frankl, 1959; Bertalanffy, 1968; Rogers, 1969; Varela, 1979). In this commitment it must be noted that although to grow and experience life fully is seen as a fundamental human desire, environmental or personal factors may block or hinder the individual.

My own journey undertaken in the present research project involved the search for a philosophical foundation which illuminates the individual's efforts to make meaning and to understand in science learning. That the person comes to the classroom with the desire to make sense of the world has been the core assumption of this work.

Driver and Erickson (1983) suggest that studies in science education would also be more valuable if there were more projects which would provide an integration of problem "driven," or problem motivated research and theory motivated studies. This would require that at the same time that we attempt to address real problems in educational settings, we must recognize and clarify the fundamental philosophical views which motivate and guide our studies. Linking the two would also require that we take theoretical positions which could have the potential to make a change in practice. The present research project is an attempt to integrate a study of the real problem of the students' difficulties in learning science with theory by conceiving of the project in the framework of the theoretical commitments of a constructivist approach to learning.

I found in the work of George Kelly a philosophical position, a theory, and a research approach which illuminates the individual's efforts, yet respects the wholeness and integrity of the individual.

4.4 Basic Views of George Kelly's Constructivist Position

George Kelly's (1955) evolving "personal construct psychology" has been a particularly useful framework in the development of this study. Kelly's work provides insight in this study through his primary emphasis upon the importance of the individual person's interpretation of the events of his world. Kelly advocated a research attitude or approach and research tools which would engage the person in conversation regarding these interpretations. These tools, and others which build upon the same philosophical base are described in Chapter 5. Their use allowed a study of how individual children's ideas change and grow as they interpret and construe the events in their classroom environment.

George Kelly's theory focusses upon individuals and their interpretations of events - not upon the actual events themselves. His fundamental postulate states that "a person's processes are psychologically channelized by the ways in which he anticipates events." Bannister and Mair (1968) point out the care with which Kelly worded this fundamental postulate:

> Kelly was careful in wording the central statement of this theory to surmount or avoid three of the most persistently knotty problems in psychology--namely, why people do anything at all: why over a period of time, or at any choice point, they do certain things rather than others; and how people who are so obviously different in so many ways can yet be compared within some consistent conceptual framework.
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> p. 10

Time is viewed as an important factor in the way in which people construct their worlds. As time passes, the person notes a repetition in events, and the recurrence of themes in events, which he or she uses as a framework through which future events and occurrences are anticipated and expected to proceed. Kelly saw the person developing predictive powers over time:

> Once events have been given their beginnings and endings, and their similarities and contrasts construed, it becomes feasible to try to predict them, just as one predicts that tomorrow will follow today.
>
> p. 53

According to Kelly (1969), "the open question for man is not whether reality exists or not but what he can make of it." Application of Kelly's work in the educational context seeks to incorporate the student's viewpoints into the teaching/learning dialogue. In its focus upon the individual person and how he constructs meaning, Kelly's work is essentially an attempt to integrate a theory of knowledge with a theory of personality.

4.5 The Person as a Form of Motion

Kelly saw the individual as essentially "a form of motion." He suggested that human experience is constantly changing as one experiments with the events of one's life and one's reactions to events. Kelly stressed the idea that people understand themselves and their surroundings by anticipating future events through their construction of tentative models of events and phenomena. Kelly found the metaphor "the person as scientist" useful in describing the individual's behavior and approach to the changing circumstances.

Kelly suggested that phenomena and events are subject to as great a variety of constructions as our minds allow us to construe. He rejected an absolutist view of truth, but pointed out that although the individual's construction of reality may not be convergent with reality, it is reality for that person. Kelly did acknowledge that an external and independent reality exists, and considering this to be the case, some constructions of the individual will be better than others in coping with it.

In the same way, we can see developments in the theories of scientists also as tentative or provisional, open to reconstruction as the individual notes new or changing patterns in events.

4.6 Personal Construct Theory and Personal Change

Kelly (1963) explicitly rejected a view of change in persons in terms of what he called "push theories based on stimuli" and "pull theories based on needs." He envisioned change in persons not as a result of external forces bearing upon the person, as if the person were an unthinking object, but as a result of the ways the person himself or herself reconstrued situations. One of the chief priorities of Kelly's orientation was the explanation of social phenomena based upon an understanding which not only takes the individual into account but asks the individual what his or her ideas are concerning the meaning of an experience. If one is to change, Kelly suggested, one must first become aware of the ways in which he or she is construing the world. Then the person must desire the change, and then make the effort to change him or herself.

There is much potential in the application of Kelly's work in promoting conceptual change in science learning. The research approach itself with its framework for conversing with the individual also can serve to help the person to clarify his or her own construing of reality. As he or she participates in conversation, Kelly suggested that the person, with the help of a caring guide, can discover his or her own ways of construing of events. Because the guide also makes an effort to understand the person's construing, this is a collaborative effort. The person is not told what he or she believes or how he or she is construing events, but an effort is made by both parties to understand, through conversation, how the person is making sense of the circumstances in which he or she finds himself.

This collaborative encounter and the emphasis upon the integrity and dignity of the individual's maintaining the responsibility for change in his or her own life circumstances are the chief contributions of Kelly's theory, and they also distinguish it from the behaviorist theories dominant during his era. Kelly emphasized the importance of understanding the meanings which individuals ascribe to their own experience, as opposed to what researchers or theorists say about the meaning of a situation for an individual. The research findings of work which employs this philosophy remain sensitive to the existential world of the individual (Pope, 1982). Kelly's personal construct theory has been described as both an ethnographic approach (Magoon, 1977, Pope, 1983) and as a phenomenological approach (Gilbert and Watts, 1983).

4.7 Knowledge Construction, Scientists, and Learners of Science

Although the creation of new knowledge in science and the learning of science are very different activities, there are parallels between the students' construction of meaning in science learning and the scientists' construction of knowledge about natural phenomena.

Toulmin (1960) pointed out that the historical development of ideas in geometrical optics has often been called a "scientific discovery" but it is, upon closer view, a new way of construing facts which had been established previously. There were no new facts "generated." What was new was the way that the facts were construed or organized. It has been said that the true achievement of Galileo (Redecker, 1984) was that he "ventured to describe the world in a way that we do not experience it." Indeed it is often a wholly unique and personal view held by a single individual which has led to a new orientation, a total reconstruction of the entire way of looking at a field of knowledge. Such insights are exemplified in the work of such scientists as James Watson (Watson and Crick, 1968), Barbara McClintock (documented by Keller, 1983), and Albert Einstein, (documented by Clark, 1981).

In their school study of science ideas, children are often asked to accept the ideas of scientists which are presented to them as the true explanations of phenomena. But just as new explanations for events and phenomena are not immediately evident to colleagues of those scientists who present a new way of organizing information, scientists' explanations for events and phenomena do not immediately make sense to young students. It has been clearly demonstrated through numerous research projects that children embark on the study of natural phenomena in the classroom with ideas about the nature of phenomena already formed through their own background and experiences (Driver Guesne and Thibergen, 1985; Osborne and Freyberg, 1985). These ideas are often inconsistent with currently held scientific ideas about the nature of phenomena. Research also indicates that a natural tendency of the learner under such circumstances is to cling to his or her own ways of viewing events, because these ideas at least do seem to make sense.

We should recognize, however, that we are not only asking children to accept new ideas, we are asking them to accept an entirely new approach to looking at events and thinking about natural phenomena. We are asking children, therefore, not only to accept what seems to them to be odd ideas, we are also asking them to have faith in the scientific explanation for events even though these explanations may contradict what they know through their own experience.

The research study was designed to allow careful listening to document the thoughts and feelings of young children who are learning about the topic, light. Learning about light presents exactly the types of challenges to intuition and experience which have been outlined here. The study is also built upon the view that it is not only specific ideas about the nature of phenomena which affect the student who is attempting to learn science. There are many other factors which children hold prior to instruction which also influence learning. Some of these are the ideas and beliefs which influence the ways that students view not only the content of their lessons, but factors such as the nature of science learning itself, the authority of the teacher, their ideas about their interactions with other students, and about themselves as science learners.

4.8 The Goals of the Work

There has been much debate among those interested in the alternative framework literature concerning what are the most important goals of this work. One view is that the chief goal of all efforts should be that students change their ideas to those of scientists. A different view is that teachers and students should, through this work, gain insight into their own learning processes and the nature of understanding in science itself. Controversy concerning the acceptance of new ideas from without and develpment of ideas from within is not new in education, as noted by Dewey in 1913:

> The history of educational theory is marked by opposition between the idea that education is development from within and that it is formation from without.
>
> p. 67

The present study emerges from an interest in looking at children's development in science not as one of these ideas or the other, but rather as an important interaction between both perspectives. Using George Kelly's work, the study seeks to illuminate how childrens' anticipations and expectations about the nature of science learning, or that which comes from within the child, interacts with the formal presentation of content knowledge in school science, or that which comes from outside of the child.

New work and writing in the philosophy of science and studies which reinterpret approaches to construction of knowledge in science, particularly the work of Bertalanffy, 1968; Bateson, 1971, 1979; Capra, 1982; Jantsch, 1980; Briggs and Peat, 1984; and Varela, 1979, has promoted the idea that human beings create the world which they perceive, not because there is no reality outside of our minds, but because we select what we see or notice in accordance with what sort of world we believe we live in. Science educators may not realize that they often, in fact, ask students to change their beliefs about the world that they live in. For a person to change what Bateson refers to as one's "epistemological premises," he or she must become aware that what is perceived as reality may not necessarily be real, indeed that there may be a great deal more beyond one's perception of reality, that is, reality may be entirely different from what we believe it to be. In a way similar to that of the scientist who constructs the meaning and interepretation of an event, children not only hold specific ideas about phenomena prior to instruction, but the ways that they participate in the construction of new ideas and organize ideas is influenced by their expectations about learning science. These expectations and anticipations about science learning are also held prior to instruction.

The viewpoint promoted in these new views about explanation in science acknowledges that observations, theories, and hypotheses are constructions of human logic and imagination. In a similar way, students must construct new meaning in science learning, when they are confronted with ideas which conflict with their own. Many scientists are aware that their own implicit theories about the nature of phenomena strongly affect the types of observations they deem important, ultimately affecting their description and final explanations of events. These implicit views are often shared by many members of a research community yet are not always explicitly acknowledged in the report of research findings.

The child's epistemology, or views about knowledge in the classroom, often intuitively held, influences what he or she will pay attention to, regard as significant and worthy of questioning, or what he or she may wish to know more about in his or her study of science. These views are usually not known to either the pupil or the teacher.

4.9 Using the Construct, Personal Orientation To Science Learning To Understand Childrens' Experience During Their Classroom Study of Light

This research project has been a serious attempt to illuminate aspects of the interweaving of factors of student orientation to science learning which affect idea development. The children's personal orientations to science learning are described along with their developing ideas about the nature of light. In this chapter, the philosophical assumptions which have guided the collection of information for analysis and interpretation in terms of personal orientations to science learning have been clarified. Personal orientation to science learning is a construct which was explored as a tool to convey the story of each child learning science. The construct is based upon the assumptions and goals of personal construct theory.

I believed that orientations to science learning would be found in the study to be highly personal. However, there would also be many aspects of individual childrens' approaches to sense making or construction of meaning which would be shared by several children in the class. What was key in the present study was planning the effort to recognize and delineate recurring themes within individual childrens' approaches to the study of science. These themes would then be used to organize and revisit each individual case report. Once these individual approaches were documented, reflection on the implications for becoming aware of personal orientation of students in this way could be considered and suggestions made for teachers interested in helping students to become aware of their own approaches to science learning could be made. Ultimately, this work would assist the student to take more responsibility for his or her own learning.

Because the illumination of personal orientations to science learning was planned to be accomplished through conversing extensively and in many different ways with children, skill and care in listening to students as they spoke with me, with one another, and with their teacher, became a crucial aspect of the study. Because both the research and teaching implications of mindful, attentive listening became clear as the study progressed, it was valuable to carefully consider the attitudes and listening tools which are appropriate in a consideration of the emotional as well as the cognitive aspects of educational research and teaching. These are presented and discussed in Chapter 5.

Chapter 5

"A GUIDE TO SENSITIVE LISTENING:" ATTITUDES, TOOLS, AND PROCEDURES APPROPRIATE IN THE STUDY OF THE WHOLE PERSON

5.1 Introduction

Chapter 5 describes the research attitudes, tools, and procedures used in the present study which are suggested and inspired by the philosophy of Personal Construct Theory.

First, the basic research foundation for the collection of information and the acquisition of knowledge is described as the "I-Thou Paradigm" (Buber, 1955). This paradigm emerged during the time that George Kelly developed his theory, as a humanistic alternative to the behavioristic models of Kelly's time. The I-Thou paradigm stresses the importance of the quality of the relationship between the participants in the study and the researcher. Use of the attitudes and tools of Personal Construct Theory depend on the satisfactory development of this relationship.

The principal means of information gathering for the study has been various forms of conversation. Informal conversation, video stimulated recall discussion and Repertory Grid conversations have been the principal forms used in the study. Concern for "sensitive listening" emphasizes the value and importance of conversation in the project, and leads to a discussion of the ways that children use language to explore and clarify ideas, and to construct meaning in the science classroom.

Procedures which I used to become acquainted with members of the classroom and children who eventually constituted the study group are described in section 5.9. The application of the technology of video recall sessions is then discussed followed by a description of the special adaptations and use of Repertory Grid Technique. This technique is the research approach most frequently associated with Personal Construct Theory. Use of the Repertory Grid in the present study have been valuable in allowing access to students' language and ideas about science learning, but actual conversation, participation with students, and the use of other techniques have also been very useful in providing insight into each child's personal experience in science learning. Repertory Grid technique and my adaptation of its use is described by taking the reader through the steps which I followed in introducing it to and using it with the children.

5.2 Acquistion of Knowledge Through the "Interpersonal (I-Thou) Paradigm"

Maslow (1966) observed that the study of human beings, a relatively new undertaking in 1966, had a history of just over a century. During this time, the "scientific study" of the human being was approached largely through the application of research methods which had been originally designed for gathering information on physical objects, that is, impersonal, inanimate things. Maslow suggested that a different kind of insight into the human being might be gained through the use of a more appropriate paradigm for study of the whole person. Maslow built his thinking on the philosophy of Martin Buber (1955, 1958), and referred to this model, using Buber's terms, as "the interpersonal (I-thou) paradigm."

George Kelly (1955), also writing at the time of Buber, put forward a model of methodology in Personal Construct Theory which essentially embodied the interpersonal paradigm. The absolute core value of Kelly's (1970) world view was concern for understanding the wholeness of the individual person rather than aspects of the person:

> ...our first consideration is the individual person rather than any part of the person, any group of persons or any particular processes manifested in the person's behavior.
>
> p. 6

Kelly also suggested research attitudes and tools for development of insight into the whole person. But the essential point, Kelly argued, is that we will understand more about people, particularly over the course of time, if thinking is centered on the idea of the person. In the present study, to research the person implied, then, the need for development of a close rapport between me and the children in the study.

5.3 On Relationship: The Researcher and the Child in the Study

If the guide and tools for sensitive listening are to enable understanding of the person as suggested by Kelly, an attitude of caring and trust is required. Maslow (1966) described the type of relationship required in such an encounter:

> In such relationships it is characteristic that the knower is involved with what he knows. He is not distant; he is close. He is not cool about it, he is warm. He is not unemotional; he is emotional. He has empathy, intuition for the object of knowledge, i.e., he feels identified with it. He cares.
>
> p. 113

Gadamer (1975) remarked that use of the interpersonal paradigm requires that the researcher does not overlook what the child says, but listens "caringly, carefully, and openly to the child." Such listening does not merely survey or assess the child. The approach to listening reveals something about the child and reveals something of the researcher as well.

For Buber, (1955) dialogue between two persons is a mutual unveiling in which each person is experienced and confirmed by the other as who one is for oneself. In order for participants to share their thoughts and feelings with one another, they must trust one another.

Erick Erickson (1975) called a basic sense of trust the fundamental prerequisite of mental vitality. By trust, he writes, "I mean an essential trustfulness of others as well as a fundamental sense of one's own trustworthiness." In the present study, careful attention was taken to allow time to become acquainted with students and to let the children understand my purposes and interests in conducting the study. This time was crucial to the development of an atmosphere in which the child and I could speak at length and to some depth about school experience. Later I was able to apply some of the more special tools and procedures of Personal Construct Psychology.

5.4 The Attitudes and Tools of a Personal Construct Theory Approach

George Kelly portrayed his entire theory, its various corollaries and related techniques, such as the analyses of self-characterization and the Repertory Grid Tests as "a guide to careful listening designed to discover the full import of the person's thinking, that is, why one construes what one does as the right thing to do" (Kelly, 1955, pp. 71-72). The techniques which Kelly suggested to attain this knowledge consisted of a variety of conversations which would allow individuals to describe their own experiences and dilemmas using their own language. In the present study, the addition of video recall technology and participant observation techniques were found to complement and aid in the search for patterns in the childrens' experiences.

5.4.1 "Kelly's First Principle": Self-Characterization

Kelly remarked that if he were to be remembered at all, he would prefer it to be not for the invention of Personal Construct Theory, but for what he called "Kelly's first principle, self characterization." Self characterization results from inviting the person who we are attempting to understand say something directly about him or herself. Kelly placed high value on the direct personal statements made by the individuals with whom he worked. In applying this approach in personal counselling, he summarized the first principle in the following statement: "If you want to know what is concerning a person, ask him, he just may tell you." This approach was unlike the psychometric evaluation procedures of his time, which constructed oblique questionnaires designed so that what was being measured was completely hidden from the individual. Kelly felt that what the person had to say about himself or herself was at times more significant. In the process of discussion with a caring guide, he believed that both the individual and the guide could achieve an understanding of the person's view of the situation which the individual was attempting to cope with. Repertory Grid

Technique was a less casual, more systematic form of conversation, but one which allowed the student to use his or her own language and forms of expression to describe various aspects of the school learning situation.

5.4.2 Conversation: "The Heart of the Process"

Conversation has been the basic form used in the attempt to understand the child's experiences. Analysis and reflection on conversations with the six children in the study group were the basis of the case study reports. In undertaking the conversations, I also adopted what Kelly referred to as an "attitude of credibility." This attitude is based upon the belief that what the person themself says is true and believable, that it is worth listening to, and that it will contribute significantly to understanding the person's thought and behavior.

Pask's (1975, 1976) conversational methodology and Varela's (1979) view of conversation also give high status to the meaning of the interaction between the conversants, and each points out how conversational interaction has an effect on the meaning of conversations. Varela (1979), and Pask and Linde (1978), note that a conversaton must be seen in its totality. The contribution of each party cannot be neatly delineated, but the text of a conversation is an "alloy" of participants' contributions (Varela, 1979). A conversation takes place from the perspective, linguistic tradition or culture of its participants. A conversation between two individuals is usually open to presentation of new ideas, to question, or to revision. This view of conversation is built upon the same metaphor underlying Kelly's view of persons in their "scientist-like aspects". The person is seen as a form of motion, as ever changing and experimenting with behavior. Varela (1979) writes that every statement which a person makes reflects a history of interactions which, in fact, make language possible. But the act of listening to the person also creates a history and brings forward new ideas at the same time. When participants listen to one another and speak, both can put together ideas which will allow a mutual understanding of the ways of construing experience.

In a discussion of scientific research studies, Kuhn (1977) refers to an "essential tension" which exists in the conversation between the researcher who is interacting with the traditional knowledge of a scientific field, while at the same time attempting to create new knowledge. When the scientist considers a problem, he or she engages in a type of conversation with the current or prevailing thinkers in the field and with their accumulated knowledge. The "alloy" of thought or divergence in this conversation may constitute a 'breakthough', with a new conversation emanating from the impact of the researcher in dialogue with new thinking in a field.

In my conversations with the children in this research project, I have sought a similar quality of dialogue, encouraging students to feel comfortable in questioning, challenging, or disagreeing with ideas. This openness to change and challenging ideas is not a failure or weakness of conversation but is, as Gadamer (1960) reminds us, at the very "heart of the process."

The use of stimulated video recall procedures allowed the children in the study to review their own performances in the classroom and allowed a reflective conversation between the children and me. Video technology (See Section 5.10) was not available during the period when Kelly was writing, and has been an extremely useful tool for deepening my conversation with children in the present study.

A more systematic form of conversation used in the study is the research technique most often associated with Personal Construct Theory, the Repertory Grid Test or Conversation (See Section 5.11). The Repertory Grid Conversation allowed the further delineation of patterns in the student's view of the situation by allowing the student to use his or her own language constructions to describe experiences.

5.5 The Power of Kelly's Approach for Educational Research

In some of his early work with graduate students, Kelly established a clinic which travelled to educational settings. During these visits, Kelly and his colleagues often report hearing teachers complain about specific students' behavior. The complaints were usually in terms of the disruptive influence of the child's behavior upon the teacher's life. Kelly felt that teachers might benefit by understanding how these "difficult" children described and construed _their_ experiences of being in the classroom.

At the beginning of the study, I was puzzled by the difficulties which some of the children in the study group experienced in their academic and social settings. At times, I was skeptical as to whether or not even the close rapport which I sought to establish would, in fact, allow me to gain insight into the ways that these children construed their experiences. It was in the attempt to understand the worlds of these particular children, by documenting the ways that they described their experience, that I found the research approach and the interpretive framework to be expecially effective in helping me to come to understand the individual person in the circumstances of the study.

Using the personal construct framework, behavior is viewed as an experiment, and, through behaving, _the person is considered to be asking a question or questions of_ his or her world. In Kelly's view, a person's behavior will make little ultimate sense to others unless we understand the questions which the person is asking of life circumstances. The child's behavior then, as Bannister and Fransella (1974) write, "is comparable to words which both have definite meaning, and changing and elaborating meaning at the same time."

5.6 A Constructivist View of the Use of Language in Science Learning

> The links between scientific and mathematical development and experience are well recognized. There is now a growing appreciation that one of the most significant contributions in science is in the development of children's language. Science activities place children in situations where they have to describe things, extend their vocabulary and use words precisely.
>
> New Trends in Primary School Science Education Volume I: Edited by Wynne Harlan, 1983.

Harlan's comments underscore the importance of the role of language in learning new ideas in science. Language is not only a medium through which new ideas are conveyed, it is a means by which new meanings are constructed by children. Language can be considered not only a medium through which new ideas are conveyed, but as a means by which new meanings are constructed by children. In Freire's (1970) view, words are more than instruments which make dialogue possible, but they also contain the two dimensions, reflection and action. To use a new word is to transform one's world. For Freire, "to exist humanly is to name the world, to change it. Once named, the world in its turn reappears to the namers as a problem and requires of them a new naming" (p. 76). Though scientists frequently reconceptualize and rename the world in this way, rarely do students understand the process which scientists have participated in to conceptualize problems. In the science classroom, students are more often asked to memorize the terms which scientists have used to conceptualize problems.

Language is a powerful means by which children construe their world and represent it to themselves and to others. Halliday (1978) saw language as potential, saying that "it is what the speaker can do." Halliday suggested that what the speaker can do is equivalent to what he or she 'can mean;' hence Halliday described language as the individual's 'meaning potential' (pages 28-29).

Cassirer (1944) considered that use of language is the activity which shapes all other human activities. He believed that language gives us the power to shape our own experience, and thereby to actively create our world. This implies that in addition to the individual's use of language to create and define his or her world, language is also used by others in the person's environment to define, control, or regulate experience. Language used in this way can be used to create social, psychological or political distances between people (Freire, 1970). Clearly, in its use to shape human activity, language can be used to dominate, control, or cut people off from understanding.

In educational settings, language might also be seen as freeing and enhancing relationships in addition to its potential use in restraining or restricting involvement. Restricting involvement appears to inhibit student interest in learning, yet the teacher's responsibility for managing a learning environment demands a balance between freedom and restriction. Douglas Barnes (1975) describes this contradiction:

> At the heart of teaching as we know it in our culture lies this dilemma: every child learns best when he is finding out about something that interests him; children are compelled by law to attend school, and are in the charge of teachers who are employees responsible for large numbers of them. There is an implicit conflict between the teacher's responsibility for control and his responsibility for learning: one treats pupils as receivers and the other treats them as makers.
>
> p. 176

In extreme cases in the classroom when language is used for the purpose of shaping and controlling unwanted behavior, teachers may completely dominate classroom talk. The implicit theory in use by the teacher who uses language in this way may be that it is the teacher who is responsible for making the student learn. Another theory in use might be that of the teacher who attempts to use language to determine how students are thinking about problems. Wade and Wood (1980) argue that the teacher who encourages and values student use of language can often detect difficulties which students are having which might otherwise have remained hidden.

5.7 Children's Language as an Indicator of Personal Orientation to Science Learning

To be interested in the individual's views concerning his or her interpretation of the world is to be interested in the ways that children use language to make sense of their world. Britton (1972) comments:

> ...we habitually use talk as a means of coming to grips with current or recurrent experience. The newspaper accounts of important events will be talked about in every train and office and on every street corner. As people talk, each is relating the event to his own personal experience, his own world: creating his own personal context for it. In doing so, he is using talk to add the new event to a body of experience that exists very largely as the outcome of similar talk on past occasions.
>
> p. 30

Kelly's metaphor, "the person as a form of motion," emphasized the dynamic changing nature of the child's use of language. Kelly believed that people use personal constructs, which are essentially language constructs, as a means of "straddling the familiar and the unfamiliar." The idea of motion is central to our understanding the tentative nature of new thinking.

Kelly (1963) referred to the tentative use of language in the construction of ideas as the "language of "hypothesis." He suggested that the child's tentative, changing representation of the world is his or her personal construct system and that the modification or the 'bringing up to date' of this representation of experience is accomplished by means of talk (p. 19). We habitually use talk to go back over events and interpret them and make sense of them, in a way that we are unable to do while they are taking place. Bruner (1956) comments in a review of Kelly's work that the implications of Kelly's first corollary, his Construction Corollary, is that it is not from experiencing that we learn, but from the reconstruing of experience, that is, the ways that we think about our experience. He considered reconstruing to be an active process undertaken by the individual in order to cope with the contradictions and dilemmas of daily experience.

Britton (1972) also focussed attention on the pupil's active use of language to create a changing representation of experience, and wrote, in support of Personal Construct Theory:

> ...by various means of representation, and with the aid of language as an organizing principle, we construct each for himself a world representation: that we modify this representation in the light of further experience in order that our predictions may be better: and that we improvise upon it for a variety of reasons.
>
> p. 31

Mischel (1964) notes that since explanation in terms of personal constructs is given from the individual's point of view, it must involve the sort of concepts which the agent already understands and uses in deciding what to do. However, it does not follow that the individual is completely aware of his or her own orientation (for example, to science learning,) for personal orientation to science learning is a construction created to give meaning to the varieties of student experience observed.

5.8 The Language of Scientists' Science and Children Learning Science

Scientists communicate research findings initially with one another. New findings or ways of conceiving phenomena are shared to convey new ways of conceptualizing ideas about a particular phenomenon. Ideas about phenomena which are presented to students in the middle and later years of their schooling, remain, however, largely in terms of the language of the scientist. The student's task is to accept and understand the scientist's ideas. The task of learning scientists' language is often imposed upon students however, without an attempt to build an understanding of the thinking processes of the student as he or she attempts to learn. As students pass from primary to secondary school, science learning becomes less and less a personal experience. More and more it is based upon ideas which the student must accept from authority. In fact, most of the ideas which result from scientists' reconceptualization of facts cannot be experienced, but must be simply accepted. This often leaves students with the task of memorizing the language and ideas which scientists have developed without understanding the processes of thinking which brought these ideas into existence.

If students are to participate in the creation of their own understanding it will be valuable for them to become aware of the ways that scientists use language in the creation of new insights. Current practice which asks student to superimpose scientists language over their own without understanding the thought involved in the use of terms may be a source of confusion to students.

Vygotsky (1962) contrasted the formal presentation of ideas in school with the child's approach to ideas about phenomena. He called the formal introduction of scientists' views about phenomena the presentation of "nonspontaneous ideas." The child's notions and approaches based upon his or her life-world experiences were referred to as "spontaneous ideas." Vygotsky regarded the development of childrens' thought as a process of active and strenuous mental activity on the part of the child. The child's own inner or "spontaneous" concepts interact with the child's own "nonspontaneous" concepts. Vygotsky suggested that the two processes must be considered as related and as constantly influencing one another.

> They are parts of a single process: the develpment of concept formation which is affected by varying external and internal conditions but is essentially a unitary process, not a conflict of antagonistic, mutually exclusive forms of mentation.
>
> pp. 84-5

The present study seeks to understand not only the ideas which children have about the nature of scientific phenomena and how these interact with the ideas presented in the science classroom, but to understand how the interaction between formal presentation of concepts or "nonspontaneous ideas" interact with the child's anticipations and expectations of science learning. These "other" frameworks of understanding constitute the type of interplay between the formal presentation of ideas and the "child's own nature," which Vygotsky (1962) implores us to consider. The present study attempts to portray the varieties of childrens' personal experience which interacts with the formal presentation of ideas in science. This interweaving of thought and feeling is manifest in the child's activity in the classroom.

In the present study, features of personal or individual orientations to science study are seen as directing and guiding the children as they learn about light. Documenting these features allows insight into those aspects which are of interest to the child. The study has been an attempt to identify and reflect upon the important features of the child's personal orientation, such as, thoughts and feelings about the nature of phenomena, ideas about the nature of the learning process, expectations for science learning, what it means to learn science, the language used in the learning of science, and thoughts and feelings about working with equipment, with other children, and with the teacher.

5.9 Applying the Attitudes and Tools of "Sensitive Listening:" Getting Acquainted With the Children

I spent my first two weeks in Mr. John Ryan's grade five classroom, observing, talking with, and becoming acquainted with the children in the classroom, sometimes sitting with them at an empty student desk, standing or sitting at the side of the room, setting up and using videotape equipment, often helping Mr. Ryan, and whenever possible, participating in an activity which the class was involved in.

I had hoped that the children would begin to communicate with me freely, and would come to know me fairly well before I worked with them in the light unit. Many of the children spontaneously approached me, knowing that I wanted to know about their science interests. Some of the comments which were typical of those the children made during this period were the following:

Martin: Hi, Miss, you're really good in science aren't you? I love science! Can you teach us sometimes? Can you teach us about rockets and outer space?

Denise: Oh, you're here again today! Oh, good, then we're going to have science more now, aren't we? Oh, good, good! Are you coming all the time now?

Raini: I really like science a lot. Last year me and Julie did an experiment for the science fair and, on the different types of cola drinks there are and everybody thought it was the very best. This year we're going to do one on gerbils. Can you come when we have the science fair and see it?

The children and their teachers made me feel immediately welcome in the classroom. They spoke casually with me about the purposes and goals of my work in their classroom and asked questions or wanted to discuss science topics. Several children made a point of discussing science interests or projects with me. Raul and Lou, two brothers who were in the class, had an idea about an engine which they had decided that they wanted to build. They waited after class one day to ask me for suggestions about its design and about connecting the solar cell. Raol and Lou frequently remained after class or stopped over to see me during spare moments to make a comment or ask a question about a science activity.

Peter came over to me one day, also during a few moments of transition from the study of one subject to another, to tell me about the dinosaur collection which he had displayed in last year's science fair. He gave me some of his dinosaur drawings and invited me to his desk on several occasions during the term to see and discuss his collection of creatures, or to look at a special drawing that he was working on.

During the second week of my stay, I spent time testing the video recording equipment which I would be using with the class. I hoped to accustom the children to having the camera in the room on a regular basis. One afternoon as I was peering through the camera, I felt a tug on my elbow. Donnie was standing next to me.

"Ms. Shapiro, I would really like to know how this stuff works (pointing to the camera system) Could you tell me how this works?"

I told Donnie that my understanding of the system was fairly limited, but that I would find out all that I could about the workings of the camera system. If it was acceptable to Mr. Ryan, she could take her free period on Friday to come with me to the conference room and I would show her all that I had been able to find out about the working of the camera.

Donnie seemed thrilled by this possibility. She brought two equally inquisitive friends on Friday. We all went to the conference room, where I had set up the equipment. I reviewed the principle of the camera and the recording of sound and picture on the videotape. The girls were invited to touch various parts of the equipment, asked questions, and then each became camerawoman to record a brief segment on videotape.

As the term progressed, Donnie often approached me with a special question which had been sparked by a lesson, or which had emerged from her own experience. One day, as the children waited in line for a physical education class, Donnie asked me, "You know, Ms. Shapiro, when we were studying colored light today, um, I wondered about, um, do you know that blue light that some people have on their porches at night? Well my grandmother has that sort of light. It's outside and I've really wanted to know what that light is and how it works." Donnie and I looked for information in the library at recess, but we could not find any resources which would help us to find out more about the mysterious blue light. Later that week, I went to a hardware and lighting store and asked for product information to help us to understand more about the mysterious light. Donnie and I talked about her grandmother's blue light during the class's free time the next Friday. I encouraged all of the children in class to talk with me about their ideas and questions.

The most frequent topic of conversation which the students approached me to discuss centered around their planning for the upcoming science fair. The discussions were usually about students' past projects and what was being planned for the current year's project. The science fair seemed to have been such a personal and lasting experience for the children. This seemed to have been a science experience that the children thoroughly enjoyed sharing and reliving through discussion. They obviously looked forward to sharing it with others in the future.

I encouraged the children to speak with me whenever there was an appropriate moment during this getting acquainted time. To facilitate this, I went out for recess with students, and remained in the classroom after school, a time when students seemed to particularly enjoy talking about science. I felt that I had gained a great deal of insight into individuals' views about science learning and of their general ideas about science learning before the unit began.

After being in the classroom for two weeks, I once again discussed the purposes of my work with the class, and asked students if they would consider working closely with me on a project which was designed to find out how children learn science. Those who did not wish to participate were asked to let me know as soon as possible so that I could be careful not to include them in the videotaping of lessons, nor would they be asked to complete any of the survey forms which I would be giving to the whole class. As it turned out, one student in the class, Mary, did not wish to participate, and did let me know. However, Mary moved with her family to another city several days later, and class participation in the project quickly returned to 100%.

I sent an information sheet home to parents about my project along with requests for permission from parents for participation of the children in the study. Every form was returned with a positive response, and I continued the study by telling the class what I hoped to accomplish and asked them to complete two brief surveys. The first invited students to communicate their attitudes towards learning science both in and outside of the school setting. The second survey concerned student ideas about the nature of light, and was used as a starting point for one to one interviews with ten students selected at random. I wanted to begin to understand how students were thinking about light phenomena before the unit began. In both surveys the students also provided information which was used in the selection of the six students who eventually comprised the study group.

5.10 The Video Recall Discussions

Stimulated recall interview technique using audio tapes was just beginning to emerge at the time that Kelly was developing his theory. It was Benjamin Bloom (1953) who first used the forerunner of this technology in educational research. He attempted to compare the relative merits of two teaching methods. He analyzed the thoughts and feelings of university students during lecture classes and compared them with classes in which discussions took place. Bloom's study using audio tapes is one of the first doctoral dissertations in educational research to use stimulated recall as a research method.

5.10.1 The Validity of the Record

During Bloom's study, "Thinking in Lectures and Discussions," lessons were audiotaped and were played back for students who reported their memories of thoughts and feelings which occurred during the lesson. Bloom assumed that the student could relive a situation accurately and with vividness if presented with a large number of cues from the original lesson. His test of the validity of the method was the student's ability to predict what was going to happen next when the audiotape was stopped at various points during the sessions. Students in the study were able to recall events within two days of the original tapings, so it was felt that the recall sessions should take place within a maximum of two days following the recall sessions. Bloom also stressed the importance of rapport with the student during the interviews, and pointed out some of the difficulties involved in the individual's sharing of thoughts and feelings about the meaning of an experience. experience.

> The extent to which a student will report the most private of his thoughts is largely a function of the rapport which is established in the interview situation. Also, students do not report all of their thoughts;

> frequently they select and report only the thoughts they believe to be most relevant, or they tend to characterize their thoughts rather than report them as they occurred.
>
> p. 162

5.10.2 Research Studies in Video Recall Discussion

Since Bloom's first stimulated recall study, various researchers have made us of stimulated recall technique to collect information on a number of issues of concern to education. Some projects which have made a significant contribution to this technique and are summarized in Table 5-1.

5.10.3 Video-Taping and Recall Discussions in the Present Study

Each lesson of the Light Unit was videotaped. The camera was placed in the classroom in such a manner that the six children taking part in the study were videotaped for the duration of the study. The camera had been introduced during the getting acquainted period, and during that time, the children were encouraged to explore the equipment, watch themselves on videotape, and ask questions about the working of the machine and my purposes in the classroom.

After each lesson I reviewed the videotape which was typically 45-50 minutes in length. During the taping of the sessions, I would sit with the children, would work with them, or, at times, would write in my reflective

Table 5-1

Research Studies Using Video Recall Methodology

RESEARCHERS	RESEARCH UNDERTAKING	SUMMARY OF FINDINGS
Siegel, Siegel, Capretta, Jones, and Berkowitz (1963)	Examined the value of student thought during instruction as a valid criterion for educational research.	A positive correlation established between learner thoughts and final score on a test of material covered in lecture.
Kagan and Krathwohl (1982)	Developed Interpersonal Process Recall Technique to assist counselors and others to understand clients' affective responses. Based upon Kagan's Theory of Human Interaction	Sees individuals anticipating the behavior of others based upon their constructs of the ideas and attitudes of others.
McConnell (1970)	Used video recall techniques to assess effect-individualized learning materials.	Reports that more relevant information resulted than that provided on evaluation forms usually used.
Taylor-Way (1981)	Adapted "Interpersonal Process Recall Techniques" to train university teaching assistants.	Assistants learned to consolidate effective approaches while re conceptualizing less useful approaches.
Winne and and Marx, (1982,and 1983)	Studied cognitive processes used by students in learning tasks and compared to teacher intentions for students.	Developed "Cognitive Mediational Paradigm," proposing that student behaviors and cognitive processes during instruction mediate the effect of teaching on learning, but note lack of correspondence between cognitive processes which teachers associate with stimuli and the actual processes cued for students.
Peterson and Swing, (1982)	Used videotaping to ask for recall of motivational self-thoughts during mathematics lessons.	More successful and verbal students showed distinctive strategies. Less successful students had less ability to review own methods and procedures, but would benefit from developing deliberate cognitive strategies in approach to learning tasks.
Rohrkemper, (1982)	Used Vygotsky's concept of "inner speech" to determine thought patterns of elementary students during mathematics problems.	Noted a high correlation between the content of inner speech and success on mathematics problems.

journal. Later in the unit, I was the "teacher" for portions of three different lesson, in an effort to provide another perspective on student involvement from the teacher's point of view.

I also kept a reflective journal in which I made notes and comments during conversations with the students. I noted patterns which were emerging in the videotapes and audio tape recordings and in discussions with students and teachers. At a later time, I was able to reflect on these entries and note emerging patterns which were pertinent to the study.

During the recall discussions, the children came individually for discussion to a quiet setting in the school. The children were seated at the controls of the video-playback unit and were encouraged to stop or reverse the tape at any time during the session. I would ask a student to comment on his or her thoughts and feelings during the session. At times, this meant my taking the lead in the conversation, to inquire about observations which I had made during the lesson, or ask questions which appeared to be significant in the study.

At other times, the children would direct the conversation, making comments and observations about the videotape, asking me questions, or pursuing a line of thought or reasoning which emerged from a dilemma in the lesson which attracted the student's attention. These conversations revealed patterns in individual thoughts and feelings. These have been presented in combination with information which has been collected using the other approaches described in the study. Unities noted in this and other descriptive material and from the theoretically based Repertory Grids accounts are combined to produce case reports which are designed to portray aspects of each child's experience of science study during the unit on light.

5. 11 The Repertory Grid Conversations

The central aim in the use of Repertory Grid Technique is to reveal the construct patterning or "unique psychological space" (Bannister and Fransella, 1971) of an individual. A basic assumption underlying Repertory Grid Technique is that the psychological relationships between any two constructs for a person are revealed in a simple mathematical association between them when they are used as categories to sort out the events or objects in a person's life. In the present study, students developed constructs which were used to consider the activities of their science learning experience in the classroom. Repertory grid technique has been used and has been adapted by researchers as a technique to allow the collaboration of "researcher" and "subject." The approach not only places the researcher in the same role as the subject to an extent, but it makes them partners in the business of interpreting meanings (Bannister and Fransella, 1971). Kelly believed that in no other way could one person truly understand another.

In the present study, the uniqueness of each person's grid reflects the uniqueness of each person's view of learning science, and more specifically, of learning some of the scientific concepts of light which are very difficult for children as well as adults to learn.

The Repertory Grids were used at the end of the light unit. By that time, I had been in the classroom over a period of six months. I knew each child in the study group quite well. I was able to evaluate the children's constructs and statements in terms of what I had previously learned about them. One of the great benefits of the grid procedure was the way that it allowed each individual student the freedom to use his or her own language to describe the learning activities.

Other researchers have used similar procedures to explore common constructs or meanings relevant to groups of children in a study. For example, Beveridge and Brierley (1982) interpreted the constructs of third graders concerning their experience of the classroom setting. Their study was designed to explore common constructs or meanings relevant to the group of primary children in the study. Individual meanings were a more central concern in the present study, and the relationship established with each person in the construction of the grid was vital to this study. The children's own ways of describing events emerged during the many conversations which were conducted with the children throughout the study. It seemed particularly significant when a child's phrase or expression re-emerged and was use again during the repertory grid conversation.

George Kelly once defined reliability as "the capacity of a test to tell us what we already know." In the present use of repertory grid technique, I was struck by the coherence of each person's set of statements in terms of the way that I had already experienced each person. The combination of many different approaches to understanding each person learning science allowed a greater depth of insight into the unique meaning which each person attributed to the science study.

The elicitation and organization of constructs using the Repertory Grid took place in four sessions with the children:

5.11.1 Session One

At the end of the science unit, I met with the six children as a group. We were able to use "the discussion room," a pleasant, quiet setting in the school. We sat at a round table and talked about the types of activities and experiences which had taken place during the unit. I asked one of the students to make a list of the experiences which were mentioned during our discussion. Each group member was encouraged to contribute to the list, and care was taken to ensure that the statement was recorded in the student's own words. Amy recorded the statements. She read them back to the participants as each statement was recorded to assure that the statement was written as the speaker had intended it. In all, 45 statments were recorded. We reviewed the final list for any repetitious or unclear statements. The final list was reduced to 37 statements (Table 5-2). Although I expressed concern at the large number of statments, the students did not feel that any more statements should be deleted, and we agreed to work with all of the 37 statments.

5.11.2 Session Two

Each activity or experience was written on a separate index card. The second phase of the procedure involved meeting individually with each child. Each person was given the 37 activity cards and was asked to familiarize themselves with the cards by sorting through them, then organizing them into groups which were linked by a common feature. Together we looked at each group, and the student was asked to describe the characteristic which they had used to sort out each group.

Two cards were then picked at random, each from a different group. I asked the child, "How would you say that these two cards are similar?" This response became the first pole of a pair of constructs. In Donnie's first experience with the procedure, statement 29, was selected, 'We experiment with Ms. Shapiro's light meter,' along with statement 13, 'I hear the other kids give their ideas about light.' Donnie said that the two were similar in that "People are helping you to understand." Then a third card with a statement from the list was selected at random from the remaining set of statements and Donnie was asked, "How would you say that the two similar cards are different from this third card? " The third statement in Donnie's case was 14, "I don't understand what I'm supposed to do." Donnie responded that this was different in that "No one is helping you at all." This response then became the second pole of the construct pair. The two poles of Donnie's first set of constructs then were the following:

1. People are helping you to understand.	1. No one is helping you at all.

Often we found that a student's contrasting poles for one set of cards were nearly identical to the contrasting poles for a different set of cards. When this occurred, I would ask the student to choose the set which he or she felt best expressed her viewpoint. We then decided

Table 5-2.

STUDENT STATEMENTS OF EXPERIENCES WHILE LEARNING ABOUT THE TOPIC, LIGHT

1. Mr. Ryan tells us about light.
2. We draw diagrams.
3. Mr. Ryan asks me to answer a question.
4. Mr. Ryan tells us what we are supposed to do.
5. We experiment with prisms.
6. We experiment with light sources and magnifiers.
7. We experiment with colored light.
8. We experiment with light sources and beakers.
9. We experiment with mirrors.
10. Mr. Ryan tells me what I am supposed to do.
11. I ask a question in class.
12. I read the worksheet to find out what to do.
13. I hear the other kids give their ideas about light.
14. I don't understand what I'm supposed to do.
15. Kids are goofing around during the activity.
16. I ask the teacher what I'm supposed to do.
17. I write the answers on the worksheet.
18. After the activity we talk about what we did and correct the worksheet.
19. I think up something to try on my own.
20. I talk with the other kids in my group.
21. Mr. Ryan tells us the meaning of words like reflection, refraction, and convergence.
22. We copy down what Mr. Ryan writes on the overhead.
23. I get the right answer to the questions on the worksheet.
24. I ask somebody else for help.
25. I help somebody with their work.
26. I don't get finished with the worksheet.
27. I don't get the answers that I'm supposed to on the worksheet.
28. Mr. Ryan gives me a hint about the right answer.
29. We experiment with Ms. Shapiro's light meter.
30. I tell my ideas about light in class.
31. I experiment with other people and with Mr. Ryan.
32. Some people understand things that I don't.
33. I'm doodling while Mr. Ryan is talking.
34. I feel bored with what I am doing.
35. I'm really enjoying what I am doing.
36. I'm having trouble reading the worksheet.
37. I put ideas together to come up with the right answer.

together which duplicate to delete.

Pilot attempts to use the Repertory Grid with a group of above average achieving, highly verbal students found the task interesting and enjoyable. I was concerned, however, that in the actual study, Melody and Martin might have some difficulty reading the cards and making their choices quickly. We found that this was not a problem, however, probably due to the fact that we had all decided on the statements which would be used in the group session, and all of the statements had been written using the children's own language. All of the students in the study group found the card sorting task and making statements of pole constructs an easy and enjoyable task.

5.11.3 Session Three

The usual next step in the procedure for completing the Repertory Grids is to present the activity list and ask each student to state at which point along a continuum between the poles each activity would be rated. The recorder, usually the researcher, would then simply make a check in the appropriate box on a chart. Following pilot attempts with Repertory Grid charts, I attempted to make the task less burdensome and more enjoyable for the students in my study group, and allow them to be more fully in charge of the reading, decision making and recording procedures. A chart of each individual's 15 unique construct pairs was placed on a single sheet for each individual student. Each student was then given 37 copies of his or her own page. A line was drawn between the poles of each construct approximately the width of the page.

The students met with me in groups of three for two forty-five minute periods each. During these sessions, the participants placed an "x" on the position along the line between or close to the poles of the construct which best indicated their categorization of each of the experiences we had listed during our first session. Each of the 37 experiences was represented on a separate page of constructs.

I was initially concerned that the students would find the task somewhat tedious, but this was not the case in practice. The children seemed to enjoy the unique and personal nature of the information that they were giving, and took note of how different the charts of other students were from their own, even thought the 37 activities were a constant. The children realized also that their charts were a special way of sharing their perspectives with me. Keeping the marking sessions to a maximum of forty-five minutes seemed to be very appropriate, and ensured that the students were only absent from their regular classroom for brief periods. I assisted students with any class material which was missed during any of the sessions in which I worked with students throughout my stay. Both the students and the teacher appreciated this assistance. The number of student statements (Table 5-2) generated by the group was quite long, as has been mentioned. It could not be shortened due to our agreement to accept all students' ideas, but fewer statements of experience may have produced equally good results.

One aspect of the rating sessions which was particularly gratifying was the lack of confusion which students experienced concerning the nature of their task. Also, given that the two constructs which the children had put forth were their own statements, there were no questions or confusions about the meanings of any of the terms on the sheets. When a student did become "stuck," it was a matter of helping him or her to decide which construct most closely described the experience. The help that I offered in these situations was to ask the student, "Which construct do you think best applies in this case? What would help you make a decision?"

One of the students in the study group, Pierre moved to a school in an adjacent district at the end of the study, but before the Repertory Grid charts were completed. Pierre's mother welcomed me into the family's new apartment to spend the sessions required to complete and discuss the charts with him. I made two visits to the family's home, and Pierre seemed delighted to spend the time with with me, and asked about his friends at the old school on both occasions.

5.11.4 Session Four

The fourth phase of the work with the Repertory Grid charts meant preparing each chart for factor analysis. For this I used a principal components factor analysis program entitled "Fact 20." Munby (1984) used a similar approach in a qualitative study of teachers' beliefs about teaching.

Using the "Fact 20" program, each of the six children's construct charts were analyzed with varimax rotation of 2, 3, 4, 5, and 6 factors. Using the criteria of eigon values not greater than one indicated that four factors would be appropriate for each child. The factors were placed on cards. I then shared the four clusters of constructs with each individual child and asked the question, "Do you think that these statements go together in some way to describe your experience of science learning during this unit?" (For an example of a cluster of statements used, see Donnie's clusters, Table 6-3). Since the children had had several experiences working with cards in which I had shown them that I was interested in understanding their ideas and feelings, this was not a difficult task, and once again, all of the children appeared to enjoy commenting on their own statements.

5.12 Records of Conversations With Participants and the "Character of the Experienced World"

Conversation has been both the basic form of information gathering in the study and is the basic vehicle for the presentation of information. Through conversations we see the links which the child makes with his or her natural world, the "spontaneous" formation of concepts, and the connections which the child makes during planned teaching encounters with phenomena, or "nonspontaneous" formation of concepts.

The accounts which are presented are the descriptions and interpretations of conversations which have taken place among and between participants in the study--the children, the teacher, and myself. At times the children spoke about their out of school experience and about the ideas which they had about light and about the nature of science. At other times, the children spoke about their classroom lessons on the topic, light, which we reviewed together on video tape. At times my conversation with the children was casual, unplanned or informal. At other times, the discussion took place at a prearranged time, with an agenda in hand, as in the review of a videotaped lesson, or with the children in a group. I also spoke at times with other children in the class, with teachers and with members of the school community.

The conversations took many forms, and with the passage of time were conducted at deepening levels, as my understanding of each person's concerns became clearer, and as I checked and rechecked my developing portrait of each person. In the classroom, the children spoke with one another and their teacher. The children spoke to me about their ideas about the meaning and significance of their activities during the study of light while watching a videotape replay of their activities. Clearly, the children were not aware of the patterns which I saw emerging during the study nor of those that became clear during the analysis of the repertory grid conversations and the review of the transcripts. The findings of the study, the themes which described the childrens' personal orientations and the ways that these were lived in the study are valuable contributions to the alternative framework literature which has focussed, for the larger part, on the content understandings which the population as a whole has been known to adhere to even after instruction. The present study adds dimensions of the child's "experienced world" which deepens and broadens our understandings in the problems of science learning. These aspects are, in the manner in which they are collected and interpreted, of necessity, interpretations, and do not claim to be statements of truth which have been waiting to be discovered; they are rather constructions as they are learning. These conversations bring into view the meaning of the activity for each child, the line of inquiry which the individual initiates during the lesson, the strategies the person employs, and the questions which he or she feels it is reasonable to ask. A final conversation in the study, the development of a set of personal constructs through repertory grid technique, is a conversation the children actually have with themselves through a reflection on the constructs which they use in learning science in the classroom. As Varela (1979) points out, in this work,

> ...there is no escape from dealing with the elusiveness of human understanding, and this fact makes it evident that whatever is informative in a conversation is intrinsically codependent and interpretational.

Polkinghorne (1983) argues that "a model of research which cannot include ambiguous and interpretable statements gains precision in analysis, but it loses the character of the experienced world" (page 238). This study seeks to add the character of the child's "experienced world" to our current understandings of the many ways that children learn about and value the study of science.

Chapter 6

THE CASE STUDY REPORTS: 'SNAPSHOTS OF UNITY'

6.1 Introduction

Chapter 6 clarifies the link beteen the philosophical commitments of the study, the collection and analysis of information, and the assessment of the authenticity of the claims of the study. The six case study reports are presented following this discussion. The first case report "Donnie," is described in greatest detail as an example of the research approach and to clarify the techniques used in preparing the case reports.

6.2 The Link of Analysis, Interpretation, and the Assessment of Authenticity With the Epistemological Stance of the Research

Putting on "constructivist goggles" in the study has meant creating the case study reports through the lens of the assumption that "a person construes events by anticipating their outcomes" (Kelly, 1955). The study has sought to identify patterns or unities in the ways that each person in the study anticipates and constructs events in the science classroom. These unities are referred to as personal orientations to science learning. A unique pattern of unities emerges for each person, and yet we see similarities among individuals, a phenomenon which Kelly described and labelled the "commonality corrollary."

The main focus of the study is, however, the persistent and important unique ways that individuals seek meaning in their science study. Because the study represents an extensive period of time during a concentrated period of study about a specific subject, the children were able to describe to me their ongoing ideas and reasoning about light. In addition, the students were able to talk with me about their thoughts and feelings, anticipations and expectations for the school study of science.

A set of snapshot portrayals of science learners has been created which conveys aspects of each person's personal orientation to science learning, and at the same time, permits the reader to consider the complex interweaving of cognitive and affective aspects of learning. Using the constructivist lens in the research has meant looking for patterns of anticipation and expectation in students concerning the ongoing science experience, and to see how these patterns are lived in each individual's effort to make sense of the science learning experience.

6.3 The Emergence of Personal Themes

Description and analysis during the first period of observation in the study was based upon Glaser and Strauss's (1967) concept of the discovery of grounded theory. In this approach, after a period of preliminary observation, the collection of data and the analysis of data take place simultaneously. My purpose was both to follow and to document the ongoing experience and reasoning of the children as they were learning about the topic light, and to discuss the meaning of science and science learning with each child. This phase of the study constitutes what Freire (1970) refers to as the "decoding stage" of research in which are observed "certain moments of the life of the area -- sometimes directly, sometimes by means of informal conversations with the inhabitants." (p. 103) It was important during this period that I be present in the classroom frequently and in a wide variety of circumstances, for example, during other lesson presentations, when other than the regular teacher was teaching the class, or when the children were having recess or free time. During the study I took on the role of teacher of the class on three occasions. Easley (1982) comments on the value of the practice of taking over the class from his own experience during case study research:

> I learned more about the nature of the problems they were trying to solve by personally confronting them than I did, or conceivably could have, by merely observing their work.
>
> p. 197

This enabled a deeper understanding of the themes and the context of each child's experience, in their complexity and by what Simons (1980) refers to as social truths of the child's experience allowing us to see the range of ideas and ways of thinking about science learning:

> By carefully attending to social situations, case studies can represent something of the discrepancies or conflicts between the viewpoints held by participants.
>
> p. 59

6.3.1 The Repertory Grid Themes

The Repertory Grid conversations, as described in chapter 5, further illuminate the language which children use to describe their own experience, and provide categories in the form of personal constructs which indicate the ways that the children personally viewed the unfolding of events during the lessons on light, and how they viewed their own participation in this unfolding. Clustering of the constructs provided another opportunity for discussion concerning the children's construing of the meaning of events, and in these conversations specific themes emerged.

6.3.2 Searching the Reflective Log and Transcripts - The Development of the Individual Themes to Revisit the Study

The themes emerging from the construct cluster conversations were reviewed and compared with the themes which had begun previously to emerge from ongoing conversation with the children and from my participation in and reflection on the ongoing experience with the children. In this process, I made transcripts of each video recall session with each child. I also made transcripts of each lesson itself, with particular attention to the small group discussions. Careful review of these transcripts, of the notes in my reflective log, and of the surveys and other materials which I had collected throughout the unit, enabled me to delineate distinctive themes for each individual. In each case description, several personal orientation themes were selected as a framework for discussing the interweaving of idea development and feelings about learning science. In this way, the reader is invited to consider the personal orientations which guide and direct each person as she or he encounters the school science learning experience through teacher, curriculum, self, and other children, and how these encounters can be seen as constituting the child's initiation into the world of science learning. Each person's experience is a portrayal of an emerging personal theory about science learning which guides the experience of learning science in the school.

6.4 Authenticity: Procedures Which Enhance the Credibility of the Work

The traditional meanings of the terms validity and reliability have been based largely upon a theory of meaning which in its turn hinges upon quantitative methods for measuring the extent to which a test actually measures what it is designed to measure. Agreement upon standards of success are then clearly known beforehand by researcher and reader. However, as Terhart (1981) notes, "The methodological compulsion to quantification and standardization neglects the interpretive character of human action and interaction or, in other words, it only makes visible those elements in interaction which are quantifiable." With equal vigor, Terhart (1981) criticizes the attitude that validation in interpretive studies is a simple problem with simple solutions:

> There exists one simple form of solving the problem of validity in interpretation: ignore it or do not accept it on the grounds that objective results in educational research are impossible, and that the objectivity of quantitative, "scientific" research results is just an artificial one.
>
> pp. 152-3

Terhart argues for a serious attempt to be made to show "that there is a special form of validity or 'truth' in interpretative research. He, and other researchers (Lincoln and Guba, 1981; Reason and Rowan, 1981, Gometz and LeCompte, 1982), reiterate the argument that conventional criteria are inappropriate to the naturalistic paradigm, and that alternative criteria must be applied.

In the present study, I have given careful attention to the delineation of themes and in the clarification of the steps taken which seek, within the spirit and assumptions of the naturalistic research paradigm, to assure the credibilty of the interpretations of the research. Owens (1982) suggests specific procedures in his discussion of rigor in naturalistic inquiry to enhance the credibility of the research. His categories of procedures are labelled:

- Prolonged data-gathering on site
- Triangulation employing a variety of research approaches
- Use of member checks
- The collection of referential adequacy of materials
- Development of thick description
- Engagement in peer consultation

These categories provide a framework for the discussion of the procedures taken to assure adequacy in each category:

6.4.1 Prolonged data gathering on site

According to Reason and Rowan (1981) "any notion of validity must concern itself with the knower and what is to be known; valid knowledge is a matter of relationship." During the initial weeks of the study, I became familiar with the children and the routines of the classroom, and allowed the children to come to know and talk with me. This initial period allowed us to accept and learn to trust one another. I invited the children to call me by my first name (though none chose to). This time also allowed me to develop a relationship with the classroom teacher. He had welcomed me into the classroom because he valued the goals of the project and felt that the study was highly relevant to his own teaching, and he hoped to learn from the work. He had also expressed some initial 'nervousness about being watched,' and this period allowed him to become comfortable with my presence in the classroom.

The duration of the project over a six month period allowed for persistence in the data gathering. Persistence in the study meant immersing myself in all aspects of the children's school world, continually making notes during and after class which documented classroom procedures, observations and my reflections as time progressed. This allowed a deepening of perception and reflection upon the experience against the backdrop of not only a great deal of experience in the classroom, but through reviewing a full set of video recordings of the lessons and of reviewing audiorecordings of related experiences. The log, a set of five dated notebooks, is a reflective work, and is a chronicle of my own struggle to grasp the meaning of the experience for the children. As time progressed, I was able to check and recheck these deepening perceptions, through the many approaches to information collection which I was using.

6.4.2 Triangulation employing a variety of research approaches

Information was collected using a variety of self-characterization techniques such as surveys, end of lesson check-sheets, informal discussion, formal individual discussion, collection and discussion of written work, stories, and recall sessions during which the children and I watched and discussed videotapes of themselves learning about light. At the conclusion of the children's study of light, Repertory Grid conversations were used to gain further understanding of students' constructions and orientation themes.

6.4.3 Use of member checks

Information was continuously corroborated through informal conversation and scheduled interviews with the children in the study. In addition, conversations and interviews were held with the teachers and the principal of the school. These were audiotaped and notes were recorded in my daily logs.

6.4.4 The collection of referential adequacy materials

I maintained a file for each of the children in the study group throughout the duration of the project. All worksheets from the science lessons were kept here, and additional materials from the classroom experience, or items which the children gave me which they also felt would be helpful, such as stories, poems, drawings, reading lists, and other notes about and by the children. In addition, several files were kept for students who were not members of the study group, but who contributed insights into my thinking and who, during the study, interacted with the children in my study group.

A complete videotape record of the science lessons was maintained. In addition, audiotape records of small group discussion and of a variety of other lessons and experiences were kept.

Typically, in the elementary setting, time set aside for science lessons is shared with topics which are thought to be related to science learning. Four sets of lessons were given time from the regular science period over the course of the study. These lessons and discussions were all audiotaped. They included: 1) a set of four sex education lessons - two with the classroom teacher, a third with the school nurse and the fourth with the classroom teacher again. During two of these lessons, the class was combined with another grade five class, and was separated into gender groups for a more thorough discussion with the school nurse; 2) a presentation by a local Native Albertan entertainer, whose performance and discussion centered on the Native view of humankind's relationship with the environment; 3) a presentation on science fiction literature by the school librarian; and 4) a presentation by a local children's science-fiction author.

6.4.5 Development of thick description

Each person's personal orientation themes are presented in the case reports. Using personal orientation themes to revisit and organize the reports, examples are given which attempt to integrate insights from our conversations, and observations throughout the study.

6.4.6 Engagement in peer consultation.

The dissertation committee members proved to be valuable critics and thought provoking discussants throughout the duration of the project. Regular meetings took place with the advisor and interested committee members throughout the duration of the entire study. The purposes of these sessions were to share ongoing findings and insights, to ask searching questions and raise concerns and problems resulting from the work, and to talk about the meaning and significance of the findings in terms of the goals of the study. During the conduct of the study, findings were also shared with other interested graduate students for discussion and comment.

Following the data collection, files and records were shared and discussed with researchers and graduate students at The University of Surrey in England where thought and research has focussed on personal construct theory, particularly in science education. In these instances as well, I was able to review and discuss the specific findings of the individual cases.

6.5 The Organization of the Case Study Reports

In each case report I attempt to interweave personal orientation themes with each child's ongoing development of ideas about the nature of light. Each case study report is organized using three main section divisions.

Part I. Ideas and Feelings About Learning School Science

Part II. Summary of Ideas About Feelings About the Nature of Light Prior to the Light Unit

Part III. Personal Orientation to Science Learning: Revisiting the Study with Personal Constructs and Emerging Themes - Paradigmatic Instances of Thought and Action

The report on Donnie's conversations, experiences and ideas is the first case presented. Donnie's case report is described in greater detail than the others in order to provide an example of the research approach, and to demonstrate the techniques used to gather information in the study.

6.6 CASE REPORT I: DONNIE

6.6.1 Some Initial Observations and Impressions

The first observations and conversations with the children in the classroom were informal and unplanned. I was searching for students who would be able to communicate with me about their learning during science on a long term basis. I also hoped to work with students who represented a range of working ability and achievement, and I wanted an equal representation of girls and boys.

Donnie was working with a small group of children in a reading discussion group when I first entered the classroom. I was near her group as they talked about their task. Donnie pleaded with various members of her group to help her to understand what was meant by the expression, "evaluative questions." She turned to me and asked if I might help her to understand this expression. She invited me to sit down and join her group. The children seemed to easily welcome and involved me, and I felt immediately comfortable with the group.

Throughout my initial observation period in the classroom, I noticed that Donnie demonstrated an exceptionally intense way of listening during large group discussion in the classroom. She seemed to try to become as involved as possible in the lessons, often physically miming the teacher as he demonstrated a point. Donnie was particularly enthusiastic about responding to questions in class, and was visibly disappointed when she was not chosen to speak. Mr. Ryan, the classroom teacher, suggested to me that Donnie was an average to above average student and he could foresee no difficulties, academic or social, if I were to engage in conversation with her over a long term basis during the study. Donnie was not only approachable, but readily shared her thoughts with me, and became the first member of my study group.

The first "planned conversation" was in the form of a survey designed for the whole class (Figure 6-1). In the survey, I invited students to tell me about how they felt about learning science both inside and outside of school. I also asked them to indicate which types of science learning activities they preferred, and whether or not they considered science to be a difficult subject or an easy subject to learn.

6.6.2 PART I: Summary of Thoughts and Feelings About Learning School Science

Initial Conversations

In this first formal conversation which I had with the children on science learning, Donnie checked the middle choice, "It's okay" when asked "How do you feel about learning science?" At first glance, this response gives the impression of an attitude of disinterest, but when Donnie was asked in the next question, "Why do you feel this way?"

Figure 6-1. Survey: Getting To Know You!

Donnie's Responses

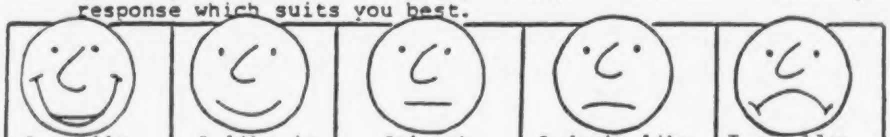
GETTING TO KNOW YOU!

Name________________________

I'd like you to fill in these two pages to help me to understand more about what you think and know about science. Remember, though, this is not a test, and if you have any trouble answering the questions, please ask for help to write in your answers. Please answer all of the questions as best you are able to! I'm interested in your ideas.

Ms. Shapiro

1. What is science? Science to me is fun with experament and diagrams.
2. How do you feel about learning science? Mark an "x" under the response which suits you best.



I really like it!	I like it.	It's ok.	I don't like it very much.	I really don't like it.
	\	X		

Why do you feel this way? I mever really liked science, though it's fun

3. Is science in school the same as science out of school? Not yet.

   If you say yes, how is it the same?____________

   If you say no, how is it different? Because out of school you learn about rocket going out to space
4. Do you study science only in school? Yes
5. Do you study science at home or on your own? sometimes
6. If yes, please tell where and tell what you do Only when I do things for the science fair.
7. What do you like most about studying science? The experaments and drawing diagrams.

8. What do you like least about studying science? I don't like it when it's hard

9. Finish this sentence. Studying science is like a fair, you have lots of fun.

10. When you study science either at home or in school, what do you like to do best?
For the activities you like the very best, mark A. For the activities that you think are just "ok" mark B, and for the activities that you don't like, mark C.

C Read the textbook
A Watch demonstrations by my teacher
C Write reports-science topics
B Do experiments on my own
C Do science worksheets
A Do experiments with other kids
C Read library books on science topics
A Talk about science ideas with other people
A Go on fieldtrips
A Make science diagrams and drawings
A Do science fair projects

11. Are there other activities that you like to do in science either at home or in school? If so, please list them

12. Mark one answer below which finishes the sentence,

For me, learning science is
____ very easy
____ fairly easy
____ fairly difficult
____ very difficult

I really don't Know, sometime it's easy, sometims it hard.

she wrote: "I never liked science, though it's fun."

I was interested in the apparent contradiction in her feelings about science learning as indicated in "I never really liked science," and yet, "though it's fun." In our first interview, Donnie commented:

> I really like science, and I usually get good marks on it. Sometimes it's difficult though, um. Some science projects I've been on were quite easy in the smaller grades, but, um, I really enjoyed it. This year it's getting a little bit difficult, but I still like it.
>
> When I was younger, I always knew what she wanted, but this year, I don't really understand some things. Like, um, before you came, we were doing the electricity unit, you know, where you light the bulb with the little bulbs and wires and batteries, and but, I still didn't get how the light went on, I know there's electricity going through. But I still didn't get it.
>
> I thought that it was fun to make the diagrams and experiment with them, but I just didn't understand how it lit. I just never really got it.

Donnie repeated her feelings concerning the unit, "Batteries and Bulbs," and commented that she felt that she often did not understand in science class. I asked for some further clarification:

I: Do you feel that it was explained and that you really didn't understand? It sounds like you are saying that it was never explained.
D: Well. It was explained, but I never really understood. I never really did get it.
I: I've had that experience before. How did you feel then?
D: Well, I don't know. It made me feel like the other kids knew what he was talking about, and I didn't really understand it. It just didn't make any sense to me.

I: Do you ask for help when that happens?
D: Oh, sometimes, but I think, they might think that I'm pretty strange (laughs). Usually I ask, but I sometimes feel sorta dumb, you know, I think I should get it and not have to ask.

Donnie's Ideas About Ways of Learning Science

The initial survey also asked the question, "When you study science either at home or in school, what do you like to do best?" The children were given categories of activities suggested by the children in pilot studies and were also invited to suggest their own. Groupings of Donnie's preferences are shown below:

Watch demonstrations given by my teacher
Do experiments with other kids
Talk about science ideas with other people
Go on field trips
Make science diagrams and drawings
Do science fair projects

Donnie's "just ok" category consisted of:

Do experiments on my own

In the "don't like" category, she checked:

Write reports on science topics
Do science worksheets
Read library books on science topics

When we discussed the survey results Donnie emphasized that of all of of the activities she had ever undertaken in science, she most enjoyed drawing diagrams. She also spoke of the enjoyment of having the opportunity to speak up in class. The special meaning which Donnie attributed to these experiences became increasingly apparent as the term progressed.

6.6.3 PART II: Summary of Ideas About the Nature of Light Prior to the Light Unit

Introduction

A second survey (See appendix A) was given to the entire class during the second week of my stay in the school, and prior to the childrens' undertaking of the light unit. I hoped to gain some basic understanding of childrens' ideas about the nature of light prior to instruction. Stead and Osborne (1979), Andersson and Karqvist (1981), and Anderson and Smith (1983) were useful resources in the development of the questions and diagrammatic instances used in the survey.

The review of the literature shows clearly that children's views about the nature of light are generally very different from scientists' views (Guesne, 1978, 1985). It is also clear that even after instructional sequences children's views change very little in the direction of scientists' views (Stead and Osborne, 1979).

Even among scientists there have been differing views about the nature of light, but several ideas are generally accepted by scientists and are emphasized in curriculum materials. Scientists describe light as an entity which propagates in space from its source. In homogeneous space, light moves along straight lines. It interacts with objects in its path and various effects are then perceived, such as warmth, rainbow colors (as when light passes through a prism), and shadows (when light hits other opaque objects). Light travels at a specific, predictable speed. Scientists' findings also inform us that light reflects from objects not made of a light absorbing medium and that human vision is possible because the eye is designed to collect light reflecting from objects, placing light rays on the retina for eventual interpretation by the nervous system.

The questions the children were asked in this survey, which was followed by individual interviews, focussed upon four main concept areas which the teacher, Mr. Ryan, planned to present during the light unit, 1) The nature of light. 2) How we are able to see objects. 3) The nature of light beam reflection. 4) The nature of color.

What is light?

My first questions were designed to provide an understanding of the childrens' ideas about the nature of light before they began the light unit. I asked Donnie, "What is light?"

Donnie: Light. Um. It's something that shines and is bright and comes from lightbulbs and things. When it comes from the sun it's quite warm sometimes. And it comes from light bulbs as I've said. It's something that lets us see.

Where is the light in this room?

In a continued attempt to understand Donnie's ideas about the nature of light, I asked, "Where is the light in this room?"

Donnie: Well, light is all around. It's in the light bulbs overhead, and we made it just before you came with batteries, um bulbs and wires. There's also sunlight and rayses (sic). There's light in this room in the tubes (points up to fluorescent lights). And you need light so that you can see.

In these and early conversations about the nature of light, Donnie showed that she both identified light with its source and its effects, as permeating the room and also being "in the tubes". Donnie describes light as both an entity and as a condition for seeing. A review of the transcripts of some of our initial conversations shows Donnie switching from one meaning to the other, referring to light as an effect at one time and referring to its source at another time.

The line of Donnie's thought parallels everyday language usage of the term light;, for example, we commonly speak of a light bulb as an object, _the light._ But in the English language, we also use the term _the light_, when speaking about the condition or quality of light in a room.

Association of light phenomena with everyday objects

All of the children were given a list of objects and asked to check those which they felt had anything to do with light or were related to light in any way. Donnie's decisions are shown in Table 6-1. The number of total student checks given by members in the class is also provided.

Table 6-1.

DONNIE'S ASSOCIATION OF LIGHT WITH EVERYDAY OBJECTS

		Number of Students Checking	Donnie's Response
1.	ELECTRICITY	28	+
2.	CAMERA	28	+
3.	TELEVISION	27	0
4.	LASER	27	+
5.	EYES	25	0
6.	RAINBOW	24	0
7.	MIRROR	23	0
8.	STARS	21	+
9.	X-RAY MACHINE	19	0
10.	MOVIES	19	0
11.	FIREFLIES	19	+
12.	PLANTS	12	0
13.	MICROSCOPE	6	0
14.	TELESCOPE	6	0
15.	ROCKS	3	0
16.	BIRDS	2	0
17.	MAGNIFYING GLASS	2	0
18.	PENCIL	1	0
19.	CANDY	1	0
20.	CLOTHING	1	0

None of the six children in the study group checked the term, "telescope," as being associated with the light phenomena. Of the group who checked "camera" and "x-ray machine", all individuals stated that they had done so because they associated a flash of light which they believed that they recalled seeing when both items were used in their presence. In fact, no flash of light accompanies the taking of an x-ray, and very often there is no flash of light accompanying the taking of a picture with a camera. Pursuing this further, I asked if there were no flash in either case, would the camera and the x-ray machine still be classified as associated with light? All students in this group said no. This response suggests that the children only associate these devices with flashes of light which are visible to them.

How Does Light Allow Us to See Objects?

Each member of the study group was asked to make and then describe a diagram depicting how light enabled a child in the following drawing to see the house:

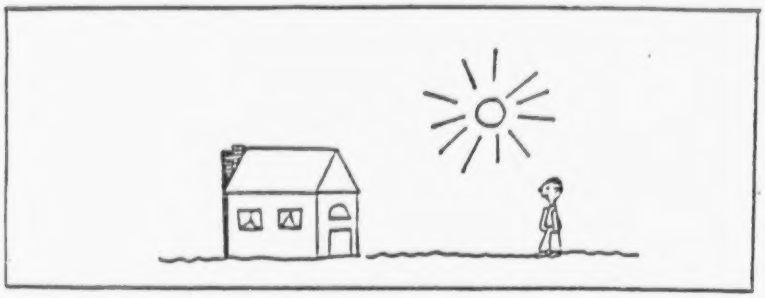


Figure 6-2. How Does Light Allow Us to See Objects?

Donnie drew the following diagram:

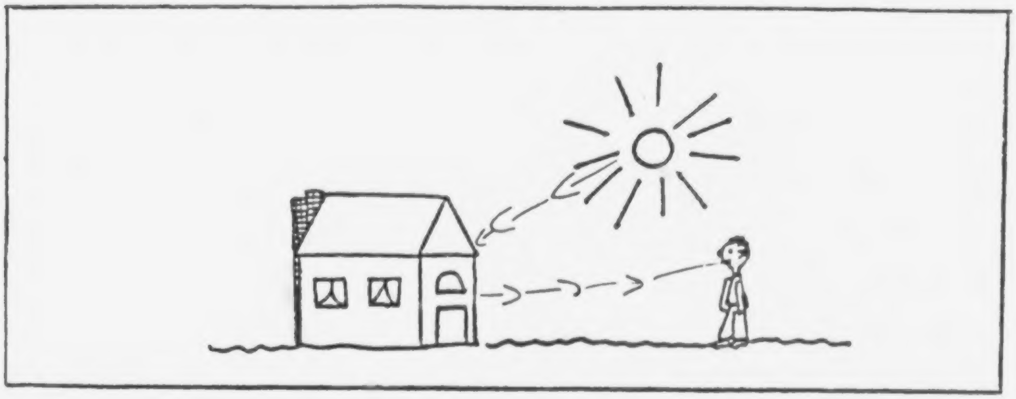


Figure 6-3. How Does Light Allow Us to See Objects? Donnie's Response

In Donnie's diagram, the light rays emanating from the sun go to the house. Rays of light are also shown coming from the house, then going to the boy. Donnie's diagram and her response to this question during our discussion was quite different than the other students in her class. The most common response in diagram form given by Donnie's classmates was to show a light ray emanating from the sun, then striking the house. A second ray then originated from the boy, also struck the house. Donnie's response was closer to the view put forward by scientists.

I asked Donnie to explain her diagram to me:

Donnie: Well, the boy sees the house because the, um this is what I was told, that the rayses from the sun fall on the house and bounce off of it to the boy.
Ms. Shapiro: Oh, you say you were told this.
Donnie: Well, yes I think um last year when we were

> opening a light bulb, doing some things with light. Or maybe in third grade. I remember learning that. A teacher said that.

Donnie recalled that this idea came from a teacher, and she has used this authority, not her own opinion or personal judgment to give credibility to her answer.

What Happens When Visible Light Beams Travel to An Object?

In this question, a set of diagrams was presented in which a series of flashlights shine visible beams of light onto different objects. The children were then asked to show what happens to these visible light beams when they come in contact with various objects. Donnie's responses follow:

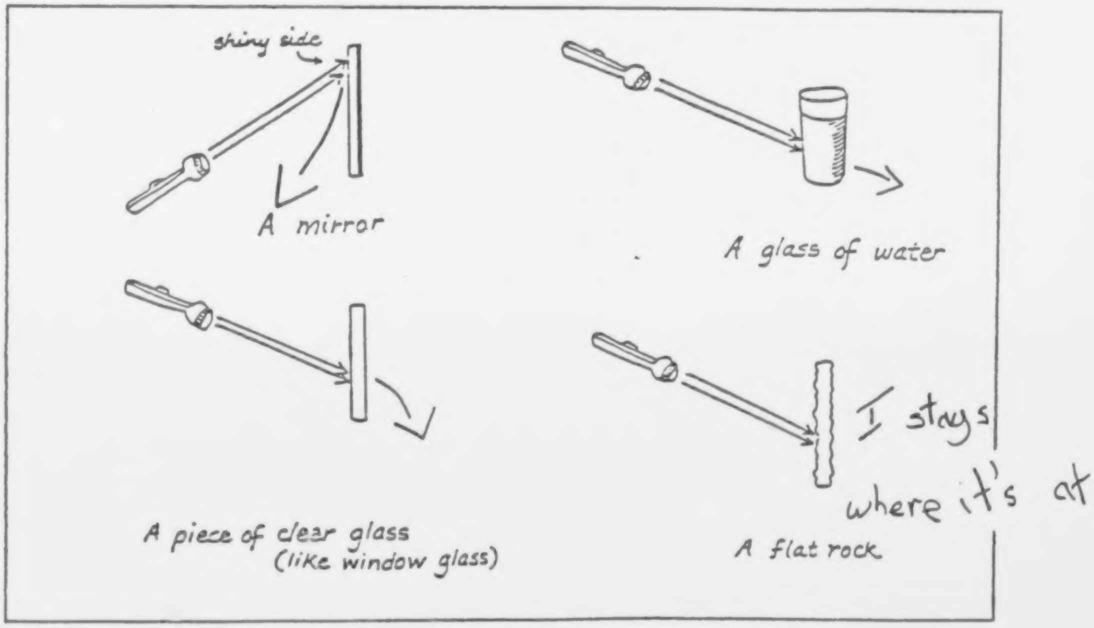

shiny side
A mirror
A glass of water
A piece of clear glass
(like window glass)
A flat rock
I stays
where it's at

Figure 6-4. What Happens When Visible Light Beams Travel to An Object? - Donnie's Response

In the final example, Donnie wrote that "The light would stay where it is" when it strikes the final example, a flat rock. In an interview after the survey, I asked Donnie in each instance what would occur if a person were standing near each object. I wondered if she would then describe the behavior of the beams of light in the same manner. Her response was "yes" in all instances except in the case of the flat rock. In this case, she answered:

> Um here. I'm not sure, but the beam would have to go to the person if the person were standing there.

Once Donnie had made this response, she went back on her diagram of light beams striking the glass of water and said that the beam in that case would have to bounce back to the person standing near it. She added, however, that this would occur only when a person was present. If a person were not present then the beams would "just stay right where they are."

From these examples, it is again clear that Donnie accepted only to some extent scientists' ideas about the behavior of visible light rays and opaque objects. She apparently based her thinking not only upon the scientist's viewpoint, but also upon her own memory of sensory experience, for unless a person were present in the last example, she apparently would not believe that the light rays are reflected from the rock. In order for her to say that the light rays are reflected from the rock, they must be seen by someone to be reflecting from the rock. It is possible that Donnie's view that events do not occur unless they are observed may be generalized, extending to and creating confusion for her in the grasp of other concepts in science.

How do we see color?

In this interview activity, I showed each of the children in the study group four thick sheets of plastic, one colored red, one blue, one green, and one yellow. A light was shone through each piece of plastic. When the light passed through the plastic and was projected onto a white piece of paper on the table, I asked Donnie if she could tell me why she thought that the result was that we saw blue on the white piece of paper.

Donnie: The plastic turns the light from the flashlight blue. It makes it blue.
Ms. Shapiro: I wonder how does this happen?
Donnie: Well, um...I'd say that when the ray hits the circle and that it makes it blue.

Ms. Shapiro: Okay. I see.
Donnie: The blue is in the way of the light and it colors the light.

Donnie's idea is typical of the viewpoint of her peers. This idea appears to be common among many children, and, in fact, was the accepted scientific viewpoint at the beginning of the seventeenth century (Ronchi, 1970). Light and color were believed to be separate entities. Color was at that time thought to be a property of the surface of objects made visible when light was shone on the object.

Feelings Associated With Light and the Study of the Topic, Light

The children expressed a number of feelings about light during the light unit, in particular, during the prism activity, the rainbows produced brought squeals of "oooooh, pretty!" Certainly, feelings experienced during an actual participation wth phenomena are expressed more readily than memories of phenomena, but the children were able to recall some feelings associated with light during our initial conversations. I told Donnie that I have a pleasant little nightlight in my kitchen that makes me feel comfortable at night. She shared this thought with me:

> Ummm. At night, just before I go to bed, you know, like, you look at the door and you see that little line of light, so you know your mom and dad are still up, and you can hear their voices, and that's sometimes sort of creepy because the room is so dark, and I think there's something under my bed! (laughs)

Donnie was able to recall other events and feelings associated with light.

> I think of cheerful, sort of, like our Christmas lights? There're really bright light that just makes your eyes go iiyaaaah..like when someone pops a flash at you, and oooooh, for about a half an hour you see this blue spot. I hate that, when it's too bright like that.

I extended the discussion of the feelings which the children associated with light to the thoughts and feelings which they had associated with school study of the topic in the past. Donnie stated that she recalled studying light in the second and fourth grades, and that it was last year that she had learned about light ray reflection off all objects.

> In grade two we must have studied it because I remember this part where the teacher did all kinds of really cool things with the flashlight. And we made shadows with the overhead projector of stuff that we couldn't tell what it was at first? Then we had to sort of guess, based on the shape, what it was. Then she showed us. Last year we didn't do too much with it. We were looking at light bulbs one day, and what was inside and all. Then the teacher drew an eye and a person...no, um, just the eye and some things the person was looking at, and told us about it. But, (laughs) you know, I really didn't get it. Well, I sort of did.

I asked Donnie if she recalled enjoying the study of light in the past.

> Well, I guess I did. Really, cause it was sort of fun to play around with the flashlight and make the shadows. It wasn't my most favorite subject, but I liked it I guess.

I took each of the children in the study group into the school library to review the selection of books which were available on the topic, light. We sat at one of the round library tables with the selection on the table.

Ms. Shapiro: Have you ever checked any of these books out?
Donnie: (Laughs) No. But I think our teacher had that one in the room once. (She points to a book entitled, Light and Color).

Ms. Shapiro: Let's take a look through these books. Are there any here that you find interesting and think that you would like to check out some time?
Donnie: Oh, yeah. I like this laser one. It looks interesting. My mom, um, wants to be an astronaut and, um, she'd like this. This one on the experiments you can do with light at home, um it's neat. There's a light bulb cut open here. This book is on color, not light, but that looks neat. This one is for little kids (she flips through a book on light and the city).
Ms. Shapiro: None of these books have been checked out very often. Do you have some idea why kids wouldn't be checking these books on light out very often?
Donnie: Well, some of them are really interesting I think, so no, I don't really know. But, um, some of them are really boring to me, so maybe they're boring to other kids too. Like, unless you're working on a project on light, like for a report in science or maybe a science project for the science fair, you wouldn't even come to this section. I didn't even know there was a whole section on just light (laughs) So unless you're studying it and have to go here...well, I wouldn't.

Of the twelve books on the topic, light, which includes related topics, such as color, lasers, and photo graphy, only four books have been checked out more than four times. Although the school has been open for three years, this is an indication of the amount of use of books on the topic light in the school library. Donnie is suggesting that light is not a topic which she would seek information on, on her own. Unless she is working on an assigned project on the topic, she would not, on her own, even go to this section. The books which interest her concern topics relating to current technology--lasers, for example--and experiments which can be done on light. It is also of interest that Donnie expressed the view that the book on color may be out of place in the section on light. She apparently does not consider it to be a topic which is related to the study of light.

Donnie's overall feelings about the study of light in the past seem not to be overly enthusiastic. She expresses the view that she had some difficulty understanding some of the ideas presented in past classes, but has enjoyed the experimentation and class activities.

The previous interviews which took place prior to the childrens' involvement with the study of the topic, Light, allowed me to become better acquainted with Donnie, and she with me. They also provided important information about Donnie's ideas about the nature of light which better enabled understanding of her reasoning about the topic, light, her feelings about herself as a learner of science, and her social interaction in the classroom.

6.6.4. Part III: Personal Orientation to Science Learning: Revisiting the Study with Personal Constructs and Emerging Themes--Paradigmatic Instances of Thought and Action

Donnie's Personal Constructs

Donnie's personal constructs are presented in Table 6-2. These constructs are derived from statements about the activities of the light unit (Table 6-4). The procedures used to generate the constructs are described in Chapter 5 (Section 5.11.1). Donnie's ratings of the 37 activities are listed between the construct poles. Table 6-3 shows the construct clusters resulting from the factor analyses also

Table 6-2.

DONNIE'S PERSONAL CONSTRUCTS

1. People are helping you to understand.	34433333424532454433434223423333233134	1. No one is helping you at all.
2. Knowing just what to do.	3134322225312555332323251354232523342	2. Embarrassed, just about to get into trouble.
3. Doing what you're supposed to be doing.	3233222224223454232323332533222354342	3. Goofing around.
4. Going ahead and trying things.	3233332234333555331333353344223535241	4. Stuck.
5. Asking questions.	2533555542142242524333313444234254254	5. Writing things down and drawing diagrams.
6. Working on worksheets.	3233555552312323134333123232532212323	6. Working with an instrument (like a light source).
7. Working with Mr. Don.	2422444443242443524421554442331453445	7. Doing something on your own.
8. Getting the right answers.	2232232225322545212331152354332523241	8. Not understanding at all.
9. Talking about the learning with the other kids in class.	2422444444141444415521344444311423424	9. Talking about the learning with the kids in your group.
10. Understanding all of it.	2222424125233555213231252355222523341	10. Not quite getting it, but getting some of it.
11. Writing things down and drawing diagrams.	5124122224312333113244222322233234142	11. Just listening to the teacher talk and talk and talk.
12. Telling your feelings about it.	4314333233232444223454333353312455243	12. Listening, bored.
13. Easy stuff.	2212114125411545232232251444221522241	13. Hard stuff.
14. Putting the ideas together.	2212314125332545233333242544122532241	14. Being confused.
15. Knowing how to phrase an idea an say it.	2324224124422445323433252544122433252	15. Not being able to get the idea out, say it, not being able to quite phrase it.

Table 6-3.

DONNIE'S STATEMENT GROUPS

Group 1:

Knowing just what to do.
Doing what you're supposed to be doing.
Going ahead and trying things.
Getting the right answers.
Understanding all of it.
Easy stuff.
Putting the ideas together.
Knowing how to phrase an idea and say it.

Donnie's Statement: Well, I feel like I understand it in all of these because I know what I'm supposed to do and that lets me go ahead and do it and get the right answers and that makes me feel like I understand it.

Group 2:

Asking questions.
Working with Mr. Ryan.
Talking about the learning with the class.
Just listening to the teacher talk and talk and talk.

Donnie's Statement: Talking things over during the discussions after the experiments and with the teacher sometimes helps.

Group 3:

Writing things down and drawing diagrams.
Telling your feelings about it.

Donnie's Statement: These are the things that I really like to do the very best. Especially drawing diagrams.

Group 4:

People are helping you to understand.
Working with an instrument like a light source and other stuff.

Donnie's Statement: Working with the equipment helps you have a chance to get help on the problem.

Table 6-4.

STUDENT STATEMENTS OF EXPERIENCES WHILE LEARNING ABOUT THE TOPIC, LIGHT

1. Mr. Ryan tells us about light.
2. We draw diagrams.
3. Mr. Ryan asks me to answer a question.
4. Mr. Ryan tells us what we are supposed to do.
5. We experiment with prisms.
6. We experiment with light sources and magnifiers.
7. We experiment with colored light.
8. We experiment with light sources and beakers.
9. We experiment with mirrors.
10. Mr. Ryan tells me what I am supposed to do.
11. I ask a question in class.
12. I read the worksheet to find out what to do.
13. I hear the other kids give their ideas about light.
14. I don't understand what I'm supposed to do.
15. Kids are goofing around during the activity.
16. I ask the teacher what I'm supposed to do.
17. I write the answers on the worksheet.
18. After the activity we talk about what we did and correct the worksheet.
19. I think up something to try on my own.
20. I talk with the other kids in my group.
21. Mr. Ryan tells us the meaning of words like reflection, refraction, and convergence.
22. We copy down what Mr. Ryan writes on the overhead.
23. I get the right answer to the questions on the worksheet.
24. I ask somebody else for help.
25. I help somebody with their work.
26. I don't get finished with the worksheet.
27. I don't get the answers that I'm supposed to on the worksheet.
28. Mr. Ryan gives me a hint about the right answer.
29. We experiment with Ms. Shapiro's light meter.
30. I tell my ideas about light in class.
31. I experiment with other people and with Mr. Ryan.
32. Some people understand things that I don't.
33. I'm doodling while Mr. Ryan is talking.
34. I feel bored with what I am doing.
35. I'm really enjoying what I'm doing.
36. I'm having trouble reading the worksheet.
37. I put ideas together to come up with the right answer.

described in Chapter 5 (Section 5.11.4). For convenient reference, the list of experiences while learning about the topic, light is presented following this table, in Table 6-4.

As stated in the discussion of the techniques used, a factor analysis program was used to group the constructs. When Donnie was shown the groupings she was asked if she felt that the constructs listed belonged together in any way. If the answer to this question was yes, I asked Donnie to tell me in what ways. Donnie commented on all four groupings. The groupings and her comments are listed in Table 6-3. Donnie's comments deepened both of our understandings of her basic orientation to science learning. She used many of the same phrases in the creation of constructs as she had in conversation with me in discussion of her experience. Her constructs corroborate and support many of the statements which she made during the study, and allowed the selection of the themes used as a framework for the creation of the case studies.

Donnie's Themes

Theme I. Self Characterization: "I never seem to have all of the right answers, the complete answer. I know what the answer is, but I just don't get it. I can't seem to phrase it. I seem to have some of the information but not all of the information.

Researcher Image/Impression: Sees herself as inadequate as a science learner, not being able to quite grasp the concept presented but with a strong desire to participate fully.

Throughout the unit, Donnie often spoke of the feeling of not quite having all of the answers to enable her to respond during science class. Her statements in the construct groupings and the contrasting poles reflect these thoughts and feelings about involvement in the science unit, in particular, a frustration which she expressed about not having all of the answers. Examples of these constrasting constructs follow.

2.	Knowing just what to do.	2.	Embarrassed. Just about to get into trouble.
3.	Doing what you're supposed to be doing.	3.	Goofing around.
4.	Going ahead and trying things.	4.	Stuck.
8.	Getting the right answers.	8.	Not understanding at all.
10.	Understanding all of it.	10.	Not quite getting it but getting some of it.
14.	Putting the ideas together.	14.	Being confused.
15.	Knowing how to phrase an idea.	15.	Not being able to get the idea out, say it, not being able to quite phrase it.

Her statements show a serious interest and concern with understanding which has a special meaning for her. Her comments about her previous experiences with science echo this sentiment. "When I was younger I always knew what she [the teacher] wanted, but this year, I don't really understand some things." In earlier science experiences children are encouraged to develop sense awareness, to trust the senses as a validating criteria for making observations and drawing conclusions. This focus on awareness and use of the senses was predominant in the early grades, but this year Donnie is being asked to accept insights and ideas which have been put forth by centuries of accumulated and corroborated scientific endeavor. Such insights are very often counter-intuitive, cannot be personally verified, and are not always grasped by students who may not even believe the ideas being presented. Waterman (1982) studied the epistemological bases of college students' understanding of science and found that even at the university level, a similar lack of belief in ideas presented was due to a lack of understanding by students of the nature and structure of scientific knowledge. This affected students' abilities to grasp new ideas in science courses.

Donnie expresses awareness that she is not understanding, and reflects on her own processes in coming to know. During the first lesson in the program, we discussed the presentation of ideas which were in conflict with her own beliefs about the nature of light.

The Introduction to the Light Unit

The class's introduction to the light unit began with a question posed by Mr. Ryan: "Who can tell me how we see things?"

> Leon: We see things upside down? Like we really see the things upside down but our brain turns them right up again.
> Mr. Ryan: Okay, that's good. But how do we get the image in the first place?
> Leslie: With our eyes.
> Mr. Ryan: Good. Good. Any other ideas about how we see things?
> Alana: Light.
> Mr. Ryan: Light. How does that happen?
> Alana: In the dark we can't see things. You need light to see where things are.
> Mr. Ryan: In the dark we can't see things. You need light to see where things are. Oh, good, good. Any other ideas?
> Diane: In the dark you need more light to see better.

Mr. Ryan summarized the points which the students made about how objects are seen, then asked:

> Mr. Ryan: Can anyone tell me why we can't see things in the dark?
> Donnie: Because there isn't enough light.

Prior to the lessons, Mr. Ryan and I had informally discussed the research literature on alternative frameworks concerning the nature of light and the difficulty which students appear to have with certain concepts, such as the idea that light travels, that some objects reflect light rather than produce it, and that light must enter the eye to enable us to see. The teacher's edition of the materials which Mr. Ryan was using suggests presenting this concept initially through discussion, by "elicit[ing] from the students that the current way of explaining light and seeing suggests that light is something which travels from the thing we see to our eyes." (Edmonton Public School Board, 1978, p. 7). However, the class was not able to make this statement. Mr. Ryan asked the students:

> Mr. Ryan: How many of you think that we see things because my eyes are sending something out to, say, the reason that I am seeing Martin is because something is being sent out to Martin that is, my eyes are doing all of the work? (Silence. No hands are raised.) Nobody? Okay. That's good because a lot of people thought initially that that's how we saw things, that it was our eyes that were responsible for everything. It took a long time for people to figure out that light had a part in it and that it was the light that was coming from Martin into my eyes that allowed me to see him. Not something coming from my eyes to him, but light coming from him into my eyes--or whatever it is that you're looking at.

Donnie and I reviewed the videotape outside of class during our interview sessions. Donnie revealed a confusion which she was not able to express in class:

Ms. Shapiro: So, you agreed with the statement that Mr. Don made, that the reason I see Marlon is because light is coming from him into my eyes.
Donnie: No, uh-huh. No. I didn't agree with that. It doesn't make sense.
Ms. Shapiro: You say it doesn't make sense.
Donnie: It doesn't make sense...because people don't make light. It's electricity that makes light and it's the sun that makes light.
Ms. Shapiro: Mmmhmm. Any other examples?

Donnie: Well, water helps to make electricity, so that, you could say that makes light.
Ms. Shapiro: So I understand that you are saying that it's not the light from me that you see. It's the light reflecting off of me.
Donnie: Well, the sun shines on you and um, I can see you because, um, of the sun, it's not anything else. It's not, um you, it's the sun.
Ms. Shapiro: It's not me, it's the sun. So, is the sun reflecting off of me?
Donnie: No. No, the sun's not reflecting off of you, it's shining on you, but it's not reflecting off of you. (her voice trails off to a whisper)

Donnie has explained that she disagrees with the idea presented in class that light is reflecting from a person and is then reflected into the eyes of the observer. Her statements conflict with the explanation which she gave to me during our discussion before the lessons. There Donnie gave the correct scientific explanation for the interaction of vision, light and objects which she remembered learning because "a teacher said that." In Mr. Ryan's class presentation she does not apply the idea which the previous teacher gave her, because the example given "does not make sense" to her. Donnie was able to give the correct response on the survey and in our interview, but she does not appear to believe the idea completely, nor is she able to give the scientifically correct answer on the survey or in the pre-instruction interview. Donnie also was not able to use the idea. The complexity of this issue of understanding versus believing is noted in another sequence in class when she switches back to the correct view. Here she agrees with an idea presented by another student in the class in providing an explanation as to why we are able to see the moon from the earth:

> Rena: Darkness must be a place where there isn't any light.
> Donnie: Rena said that darkness must be a place where there isn't any light. I thought that was true. I was going to say the same thing.
> Mr. Ryan: Yeah. I'd have to agree with that. Darkness is a place without light. Can anyone tell me what light is?
> Marvin: The sun is light.
> Kitty: Light is something that shines.
> Melody: The lights around us are bright.
> Donnie: The streetlights are light at night.
> Carey: You can get light from a campfire.
> Mark: You can get light from stars.
> Marvin: Light can come from electricity. Light can come from the moon. It shines at night.
> Mr. Ryan: Oh, oh. I see Michael shaking his head with that one.

Donnie: Here is what Michael said. I agree with him. He said that the moon is like a mirror.

> Michael: Like, the sun reflects its light to the the moon--it comes from the sun. The moon is like a mirror.
> Mr. Ryan: Oh, good, good. Micheal said the moon is like a mirror and it reflects the light that comes from the sun so that we can see it. Good point.

Ms. Shapiro: So you are saying that you agree with that.
Donnie: Yeah. I saw that lots of times on, well, (laughs) on Sesame Street. Like it's really for babies, but I like to watch it. (Laughs). That's probably where Michael saw it, too. Um, the rayses (she uses her hands to demonstrate on the table) from the sun reflect on the moon.
Ms. Shapiro: I see. He said that the light travels from

the thing to our eyes and that's why we see it?
Donnie: Hmm. (Pauses.) Well, the light reflects on the thing and it bounces off to us so we can see it, like he said.

Donnie has once again applied the correct idea supported by the Sesame Street lesson. Yet it is quite clear from our discussion that she does not have a firm grasp of the presented idea as she does not consistently apply the idea correctly. She wants to hold and present the correct idea in class, but must deny what truly does not make sense to her. This became much clearer when Donnie expressed her views on the phenomenon of refraction which the class studied later in the unit.

Mark's Revolutionary Idea

On March 13, Mr. Ryan told me that he was going to skip Activity 2 in Section B, which dealt with light passing through liquids of different density. Mr. Ryan said that had found in the past that this lesson was not as valuable to the development of ideas in the unit. He expected that I would find that the students would really enjoy the activities in this lesson, entitled, "So Deceiving." At the end of the activity, students were to be asked to pull together several of the ideas which had been taught in the unit to date to provide an explanation for the broken appearance of the pencil in a beaker of water. At the end of this activity only one student in the class, Mark, verbally responded with the "correct" answer, and this happened only during the final minutes of class discussion. Donnie in particular was trying to respond to the question in class, and listened carefully to the comments made by the other children.

The lesson materials included worksheet instructions for the students to complete two activities and then provide a statement explaining their observations. The final activity of the two asked students to place a pencil in a beaker of water, then provide an explanation for the pencil's bent appearance. When Donnie and I reviewed the video tape of the lesson, she asked, "Can we go over the discussion part of the lesson? I want to hear it again because I wanted to answer some stuff Mr. Ryan was asking and I wasn't sure about a couple of things." We reviewed the lesson on the videotape and Donnie commented on what she found most interesting in the activities:

> Donnie: The saucer is the one I preferred. It was fun. You got to see something that was really interesting happen. And then you open your eyes and you think it's magic and, but it's not. It's just something that's really tricky and fun to find out. I also liked that activity that we did when we were predicting. [Activity 2] That was the most interesting and fun. I don't know, I might have found it interesting because I got them all right (laughs) but I thought that it was a lot of fun to make that decision, like about how the light would go. Here, (watching video) this is where I'm going to start telling what the answer is. I was just going down to try to explain my idea there. (Donnie was called up to the overhead to explain her idea.)

What happened was that you took a saucer and you put a coin in it and um, then you fill it up with water, and you have to be down on your knees so um, before you put the water in until you can't see anything but the edge of the saucer and then when you fill it up with water then you can see the coin. I tried to answer in the discussion, but my answer wasn't quite right.

Ms. Shapiro: You say your answer wasn't quite right here. I'm not sure what you mean.
Donnie: No. Sometimes I don't think that, well, that I have some trouble with science. Mostly the last unit that we did. Like I told you what we had to do was take a little tiny light bulb and we had wire and we had to figure out ways how to light this bulb and we had different activities to do and actually it was quite fun but in other ways it was hard to understand because I didn't know how they could take a little piece of wire and attach it to um, a battery and then put the light bulb on and the battery and make it light. That, that's hard to understand.
Ms. Shapiro: So you found it hard to do?
Donnie: No, it's kind of hard to understand how it all worked!
Ms. Shapiro: It seems as though you are finding the unit fun, but a bit difficult to understand.
Donnie: I'm finding it really interesting. Some of the activities are hard though. Sometimes I feel like I don't have it all, all of the information to tell what is happening.

Putting Ideas Together

As we reviewed the tape, Donnie related her effort to provide an explanation for the bent appearance of the pencil in the beaker. She describes how she believes listening to the other students in the class helped her to add to and develop her own ideas, to almost "get all of the information."

Donnie: That's Carey talking now.
Ms. Shapiro: She seems to be saying that there is only

air in the top part of the glass and that the water in the bottom is what makes the pencil look bigger. Did you agree with that?

Donnie: Well, yeah, I took a little bit of *that* information too. I took some other peoples'information and put it into mine, but I still didn't quite get all of what I needed. This is where I'mgoing to answer.

> Mr. Ryan: Can anyone think of an explanation using the words bending, light, and refraction?

Donnie: At that point I wasn't quite sure, um, how the um, how it happened. Like, um, I didn't know that there was *light* in that part

Ms. Shapiro: He asked, "Can anyone think of an explanation using the words light...

Donnie: Bending and refraction.

Ms. Shapiro: That would have given a clue, I guess, about what was the right answer.

Donnie: Yeah, but it just didn't make any sense that there was *light* in there and that that's how it makes it bigger. I'm gonna say something here...

Donnie commented that she felt that she had *some* of the right idea, but that she believes that the idea that understanding the behavior of *light* is the key to the explanation is something that she had not put together, even though she was able to tell me after the lesson that light was the key, it did not occur to her prior to the lesson.

> Mr. Ryan: What is the water doing to the pencil?

Ms. Shapiro: Right here it looks as if you were hit with a bolt of lightning. Right there. What happened there?

Donnie: I think that I just realized an answer that I wanted to give. Just, um let's watch it a second, okay? Leanne is talking about the shadow that the pencil makes in the beaker, but that's not it, um the answer.

> Mr. Ryan: Do you see a shadow? When I took the pencil out, was it the same size as when it went in? Donnie?
> Donnie: Well, the water and the glass makes it bend...
> Mr. Ryan: Makes it bend?
> Donnie: Makes the pencil bend. Makes it look bigger.

Donnie: See, there, I'm not finished yet.

> Mr. Ryan: I'm not sure that I understand what you're saying. If I put the pencil in the water and I look at it, it looks like my pencil's broken. When I take it out it isn't broken any more. Did it bend and fix itself?
> Class Members: No!
> Mr. Ryan: (Emphatically) Okay, what made it look like it was broken?
> Donnie: The water.
> Mr. Ryan: Okay. (In a louder voice) But what did the water do to make it look like it was broken?

Ms. Shapiro: You look very intense here. What was going on for you here?
Donnie: Well, I didn't know what the answer was. but I wanted to know. So I was just looking here to see what Mr. Ryan had on the overhead, so all I am doing here is copying down what he had up there. The right answer.

> Natalie: I think that it is the roundness of the glass.

Ms. Shapiro: She is saying that it is the roundness of the glass?
Donnie: Yeah, later on, Jim says that it acts like a magnifying glass. I also took his information and put it into mine, and it made better what I had, what I was thinking, but I still didn't quite get

all of it.
Ms. Shapiro: So it was Jim's information that you put together with yours?
Donnie: Only I had a little bit more than he had. I just took the magnifying glass part.
Ms. Shapiro: So you are saying that it acts like a magnifiying glass?
Donnie: Yes.
Ms. Shapiro: So the magnifying glass makes it look bigger.
Donnie: Well, (pauses) a magnifying glass is like two glasses together. It makes things look bigger.
Ms. Shapiro: How do the glasses do that?
Donnie: (Laughs) I don't know!

This conversation with Donnie took place on March 12, one day after she had heard Mark's correct explanation and had heard Mr. Ryan reiterate it. In fact, Donnie and the other students in class were required to copy down the correct explanation as Mr. Ryan had written it on the overhead projector. Although she has stated on several previous occasions in discussion with me that light is reflected from objects, in other conversations, she has stated that it is only reflected from some objects. Because she does not appear to have completely grasped the idea that light reflects from all objects, she has not used it in combination with the idea that light is bent when it passes through the beaker, even though the idea has been presented repeatedly, and was the main concept presented in the previous lesson, "Bend that Beam." In terms of a construct theory explanation, her thinking and explanation reflects the idea which is still making the most sense to her, given new examples to comment on.

Donnie's earnestness and persistence is evident in the lesson as she repeatedly tries to give her explanation in response to the question, "Why does the pencil appear to look larger?" even while Mr. Ryan indicates to her that she is not giving the correct response. Donnie persists in the discussion, and at one point, Mr. Ryan tells her that she has "some" of the idea, but not all of the idea.

Ms. Shapiro: When Mr. Ryan told you that you have some of the idea, how did you feel about that, encouraged?
Donnie: No. Just as normal as I would feel if I got something wrong. He's saying that and I'm gonna say something after him, cause I'm still talking here, so I'm not quite finished.
Ms. Shapiro: He said that you had part of it. But I think you're saying that you somehow count that as being wrong.
Donnie: Well, you know, I'm sort of right and sort of wrong, but I wanted to get it! (Laughs) My answers are never right in science.
Ms. Shapiro: You're always wrong in science?
Donnie: Well, it's usually that I'm halfway right, and in other ways I am sort of right.
Ms. Shapiro: So you know that you have some of the basic ideas?
Donnie: Yeah, but there are some that aren't there. There are some people who seem to always get it all all of the answer. Like Katy, Annie, and Carey sometimes, or Mark. Last year I got most of the answers. This year it's just a little bit hard. I don't know why. My explanation for this one, I think it's this one here, Mr. Ryan said that I was on the right track here. He said that I had a really good answer for it, but here Mark had a better understanding of it. He got all of the information. I only got half of it.
Ms. Shapiro: What was it that Mark got that you didn't?
Donnie: Okay. I'm not good at explaining things, but (laughs) well, what happened is that I thought that the water and the glass did it.
Ms. Shapiro: The water and the glass is what you said before.
Donnie: Yeah! Because I didn't think of the light. I don't know why I didn't think of the light like Mark

did. Um, (laughs), I don't know why I didn't!

Ms. Shapiro: Hmm. Well, the glass is something that you can see through...

Donnie: Yeah, you can see through it. Now I said that it acted like a *magnifying glass*. It was almost [inaudible] like this. I said that it acted like a magnifying glass, and um, it acted like a magnifying glass because the water I said was a *liquid*, and I said that the glass is like a magnifying glass, and the beaker well, the glass and the liquid together would probably make it look bigger, but I said it, um the pencil loked bent like this or something, make it bend, like, but I didn't mean that it *was* bent, just that it *looked* bent.

Ms. Shapiro: I see. You know, it sounded to me like you meant that it did bend it, too.

Donnie: You know, that threw me *right off*. I had no idea, well, what was going on, what to say there.

Ms. Shapiro: What threw you right off?

Donnie: That it wasn't um, *just* the water. At this point I didn't have any idea that it had, that *light* was in it, was in the answer.

Ms. Shapiro: Hmm. (pause)

Donnie: Because well, I didn't know what was happening here because of the light. Because you can *see* light. I just didn't have any idea that light had something to do with it. I was really surprised. I don't know how I could've come up with that idea. But I know what happens now. The light, it goes through the water and it hits the pencil, and the water and the light um makes it look broken and how it does that is that the light shines into the water, you know and you can see it, um the water, and then it goes right in and then it hits the pencil and then you see on the water line, and the it um, you can make it go down, and it's supposed to be like that, (shows me a straight finger and points to the beaker), but it goes like that (crooks her finger and points to the beaker and the pencil). I didn't explain that very well.

Ms. Shapiro: No, that was fine. How did you get the idea that light is the key?

Donnie: From what Mark said in class...in the discussion.

Ms. Shapiro: So that gave you a clue to the idea. I see, so it makes sense to you now, that it's the light.

Donnie: No, not really. But Dean said that, and Mr. Ryan said that it was right.

Donnie was able to tell me the key to understanding human vision, and has given the explanation for refraction, but she realizes that she is not fully understanding the idea. She would be able to answer such a question correctly on a quiz, examination, or survey of childrens' ideas about light phenomena, but she herself states that she does not have a real understanding of the concept.

During my involvement with the children in the study, I noticed an aspect of the design of the materials which likely served to further confound Donnie and was linked to her original ideas about the nature of light. In the presentation of concepts, most of the lessons and activities focussed upon discussion, activities, and conclusions which used visible beams of light from a light source box. These beams of light are similar to the visible beams coming from a flashlight, which the children readily relate to. Many of the activities, however, and particularly the refraction lesson require the children to make a bridge in understanding from visible beams of light to the understanding of rays of light which are not visible to the eye, and reflecting from objects without noticeably shining from them. Most of the children are not, then, able to relate to the statement that light is reflecting from all objects, not only when a ray of light can be seen to be shining on the object, but when the sun, the normal light in the room, or other indirect sources are present. Photographers must have a deep understanding of the quality and intensity of this light in order to take its effect into account in film exposure. Light meters assist in this accounting, and later in the unit I brought in a light meter and reflecting equipment to help students bridge this very difficult concept. In fact, one photographer whom I consulted commented,

> This is a very difficult idea to grasp, even photographers have a little trouble with it. I'm not sure when I myself made that leap in understanding, but when I did, the world I looked at was all of a sudden, it was different. I can take photographs, but I think I see a lot more beauty. I appreciate the different qualities of light more. The world is really made more beautiful.

"Weird Words and Funny Language"

Another aspect of the unit which was found to be a source of confusion, which was experienced but was not understood by the children's ideas about the nature of light, was the use of specific terms and conventions. This problem area was not mentioned in the literature. The long and intense nature of the study may have allowed it to be seen as a concern for students. Problems with the use of certain words were first mentioned by Donnie, then confirmed in discussion with the other children in the study group.

Donnie and I talked about the use of the term "bend" during the latter part of the videotape in which the concept of refraction had been explained.

Mark has waited until all of other explanations have been given before providing his explanation. After he gives the explanation, Mr. Ryan repeats it and writes the answer on the overhead projector. Mark has said that the light rays coming from the pencil are bent by the water.

> Mr. Ryan: That's basically what happens. The water bends the light coming from the pencil. Okay? It is the bending of the light that makes the pencil appear as if it is in a different position in the water.

Ms. Shapiro: Can we stop here? Mark was explaining things here.

Donnie: (pause) Um, well, um he said that the light hit the pencil and then would make it bend. It's the water and the light mostly I guess.

Ms. Shapiro: It's the water and the light mostly? You were saying before that the glass is somehow involved. Do you still think so?

Donnie: Yes. It has to have something to do with it I think. It must.

> Mr. Ryan: The water bends the light. The top part of the pencil was not in the water and did not appear to be broken. The top part with the air doesn't have anything to bend the light. The part of the pencil that was not in the water didn't have anything to bend the light. When the light is bent, it made the pencil appear to have moved position under the water. Good, good. So let's write that down.

Ms. Shapiro: I see that at this point you are writing down your answer. Were you understanding here?

Donnie: Well, I didn't understand it, no. I didn't understand what was needed.

> Donnie: (To Carey) What does it say after water? (referring to overhead)
> Carey: Bends.
> Donnie: That's weird.

Ms. Shapiro: You said that was weird?
Donnie: Well, there are all of these weird things, you know, like light bends. Light bends? I don't know. Light bends? How does it do that? I thought I'd see like light bending in the light source? But it doesn't. Only when it reflects.
Ms. Shapiro: You mean that only when you see the light bounce from the mirror, hitting striking an angle? That's bending?
Donnie: Yeah.

I pursued Donnie's concern with the use of the word bend when describing light to try to understand what using the word meant for her and how she felt it "weird." She explained by drawing me a light source, then a beaker of water. The rays of light passed through the beaker of water and converged.

Donnie: (Pointing with a pencil to her drawing, Figure 6-5) Say you have a light source, here, okay? Not too straight, but who cares? (Laughs.) So you have a light source there. And you have the beams. Two small beams. Okay. What happens is like say the beaker of water or a magnifier let's have the beaker of water...there's the beaker of water, and you have a mirror. Right here. The light rays would hit the glass of water. Well, they hit there and then bounce off somewhere else. But I don't think, um well what would happen would be that they would be going across like that, and then they would probably be going off like that over here. So there, they're sort of bending. They bend right here. These are what, um the convungence (sic) points? And then right there.
Ms. Shapiro: I see. So when it hits and goes off, that's where it bends?
Donnie: No. That's reflection. Actually, um the only bending point is right there. At the convungence.

Donnie had not grasped the meaning of "bend" the special way that it is used in the light unit, the idea that rays of light shining through a beaker of water are

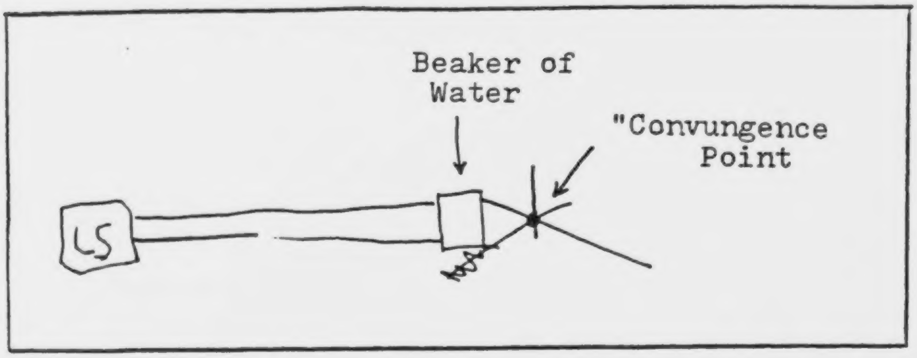


Figure 6-5. Donnie's Drawing of "Convungence Point"

angularly redirected. Here she is applying her understanding of the everyday use of the word, bend, to the effects of light, not realizing that the term has a special meaning in light science. Donnie's meaning for the word bend was no different than her everyday use of the word. She commented during an early lesson in which visible light rays were passed through a beaker of water:

Donnie: Bend, he said the light rays bend. But they only do that when they bounce off like, a mirror. Like, and go like this, (she bends her finger). Because you don't see the light bending. It has to bounce off something.
Ms. Shapiro: I'd find all of these words quite confusing for the first time.
Donnie: What do you mean?
Ms. Shapiro: Oh, well. Words like bend here. But the other terms that are newer to you are used quite a bit-- convergence, divergence, reflection.
Donnie: Sometimes they're hard to remember, but it's neat to learn new things. You know, like maybe you didn't

quite know what it meant, so now you know how to use it now.

I asked Donnie if she would talk with me about some other words which were used repeatedly, convergence and divergence:

Donnie: The beams come together and cross. They bend at this point (point 1). Convungence (sic) is when they cross. Divergence is when they go on and on and on forever and ever. (She points to the two ends of the rays.)

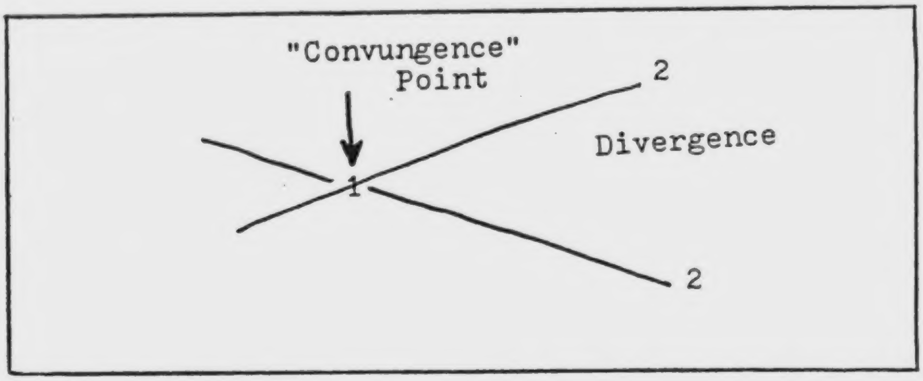


Figure 6-6. Donnie's Drawing Comparing Convergence and Divergence

I asked Donnie if the light ray bent as it passed through the beaker of water.

Donnie: No. It doesn't bend here because as you can see, it's travelling in a straight line. It bends here. (point 1)

In another lesson, Donnie commented on her fascination with new words, yet the confusion which they sometimes produced. During the review of the videotape of lesson 9, "Prisms and Spectra," Donnie stopped the tape:

Donnie: Here I'm reading it over. Right here. "Describe what you see. I didn't um, know what to do, but then, I kept moving the thing around um, the prison (sic) and I found a rainbow and I asked Mr. D if I was doing it right and he says, 'yeah.'
Ms. Shapiro: I see. You are saying that you didn't understand this but somehow you got it?
Donnie: No. I read this over here and I still didn't understand here cause they use funny language, sometimes weird words.
Ms. Shapiro: They use funny language. You mentioned that before.
Donnie: Well, the words 'rotate' and then they say, "gradually observe' and 'arrange' and things like that. (reading from the worksheet)
Ms. Shapiro: There are problems with those words.
Donnie: Well, I know what they mean, it's just that some of the things I just don't get what they're talking about. When they put them all together, like it takes so long to figure things out.
Ms. Shapiro: What does it mean to rotate the prism gradually?
Donnie: Let's see, like, to move it around slowly, I guess. (She demonstrates by swinging the prism around as if drawing a full circle with it.) To move it around like that. Move it around until you find a rainbow. I don't like all that language. And the words like arrange, proceee-dure, rotate, gradually observe, spectra. Those are hard.
Ms. Shapiro: You know what a spectra is.
Donnie: No. And I just learned what the prison (sic) is. I never saw that before. I like to learn all the words and stuff like converge. They help me to learn. I like to use them all but sometimes it's just too hard. But like refraction, oh, um, I know he uses it all the time but I just can't remember what it means.

Throughout the unit of study, I noticed that Mr. Ryan used the term, reflection at times in a commonsense manner, referring to the visible beams of light and visible images which the children actually saw in the classroom either bouncing off a mirror or seen in a mirror. Reference to ambient light rays, nonvisible rays of light which bounce off all objects in the environment, was frequently made, for example, in an activity in which students viewed the reversal of the word, "Light" written on a card as they moved the card farther and farther away while viewing it through a beaker of water. In this example, a different understanding of reflection of light rays is required, and yet, the teacher's explanation of the term, "reflection" was always the same:

> Mr. Ryan: We all know what reflection is. When you wake up in the morning and look in the mirror, you see yourself, your image. That is your reflection.

In fact, Donnie described light reflection to me in me in our discussion in a similar manner:

> Well, you take a light source and you know how when you take, um see maybe two light beams coming out like this? (She draws a picture in my notes) and then you put a mirror here and it sort of bounces off and it goes to something else. That's reflection.

Donnie's continuing description of reflection as an object, that is "a" reflection, a physically perceptible image, showed that she was not making the connection between the idea of light rays which are visible and light rays which are not directly visible to the human eye which both "bounce" or reflect off objects. In fact all of the children in the study group, with the exception of Mark, originally and vehemently denied this second meaning of reflection, because, as Donnie repeatedly stated, "Because if it were reflecting, off, you would be able to see it bounce to somewhere else.

Conducting a regular and ongoing conversation with Donnie was particularly valuable in my ongoing understanding of her lack of grasp of the ideas presented to her during the unit. Ongoing discussions with the children was the most valuable source of insight into the children's difficulties. Donnie expressed her frustration frequently, by expressing the "feeling that I'm not getting it, not all of it," but she did not know precisely what it was that she was not grasping. The confusion with words, for example, became apparent only during our discussions and not through worksheet errors. Mr. Ryan had the children correct their worksheets in class at the end of each activity. Because he saw only the corrected forms, he did not have an opportunity to see the pattern in and nature of student difficulties with the unit. Because I wanted to use the worksheets to understand the childrens' ongoing line of thought, I asked each person in the study group to use two copies of the worksheets. The first copy would contain their first written responses to questions. The corrected responses, made in class, would be written on the second sheet. In this way, a record was kept of each person's line of thought, rather than a collection of answers all identical to one another.

During the refraction lesson, I asked Donnie how she felt about making the corrections in class at the end the activities:

Ms. Shapiro: For me it would be difficult to write down the answer that is on the overhead projector when you know that it is the right answer but you still feel that you don't understand it.
Donnie: Yeah, um, it's not hard to write it down because you just copy what it, um what Mr. Ryan has up there, but it's just that I don't really get it.
Ms. Shapiro: You know that you don't understand it really.
Donnie: Yeah, but we're supposed to have it down. Maybe not the exact same way as up there [on the overhead] but we're supposed to have it down. I'm just glad to have it down right now.
Ms. Shapiro: It sounds like you were really relieved. Were you able to give an explanation for being able to see the coin?
Donnie: Well, here, for example when you pour the water in the coin saucer, the coin looks like it floats to the top, so, um but that's not really what happened. But what I think really is happening here is that well, you see, um you can't see the coin and when you pour the water in it, I think it's because the light hits the water and then it comes to your eyes so you can sort of see. I was trying to figure that out. In the tape I was trying to answer Mr. Ryan, but I just couldn't phrase it right.

I spoke to Mr. Ryan about his understanding of Donnie's experience in terms of my ongoing perceptions of her continuing effort even in the face of being often incorrect.

Mr. Ryan: Donnie spends a lot of time 'trying to make connections' as you say, in all areas. Like, she bounces a bit and she has trouble taking or making

> those connections, and putting them together and she's um, she's a little bit frustrating because she doesn't concentrate on pulling them together either. They're just kind of there, let's pick from them here and there and if that doesn't work, well, you tell me. And I tell you, then why, and oh, okay, she makes the connections once you show her the path, but she hasn't yet gotten to the point where she can take some of those connections and put them together for herself yet. But you're right, she continues to try where others sometimes just don't bother.

Here Mr. Ryan was expressing a view similar to Donnie's personal views about science learning, that is, that with the correct amount of effort, one should be able to figure things out, and thereby to make the connections by one's own effort. His honest frustration is that students are not "getting" the basic ideas of the unit. I showed Mr. Ryan the results of my questions to the entire class regarding their understanding of refraction. Mr. Ryan did not realize that the class as a whole did not grasp the notion of nonvisible light beams reflecting off all objects in the environment. Because Donnie is one of the few children who speaks up often and consistently attempts to voice what she does not understand, he has taken notice of her comments and of her sometimes unsuccessful struggle to understand. Even though the other students are not understanding, in most cases they do not make mention of the fact.

This is one of the unique aspects of Donnie's orientation to science. She is very much aware and concerned when she is not understanding in science. Because she is asking some of the fundamental questions that physicists have asked about the nature of light, her frustration is actually an indication that she is grappling with some fundamentally important issues which are extremely difficult dimply to accept when she is making the effort to attain deep and complete understanding.

The attempt by the student to seek understandin is not unique to Donnie, but the manner in which she goes about attempting to attain this understanding is, as the diiscussion of Theme I demonstrates.

Theme II. Self Characterization: "I like to talk in class and draw diagrams. Drawing diagrams is what I like to do the very best."

Researcher Image/Impression: Enjoyment in full participation in the experience of learning. Enjoyment of putting ideas together in a visual representation.

Donnie's second theme emerges as a continuing, persistent interest in finding ways to participate more fully in the science lessons. She particularly enjoys both the process of drawing and of using drawings to keep track of her ideas. During the videotape reviews of this lesson and in previous lessons, Donnie would often spontaneously ask me if she could make a diagram on my notes to demonstrate and discuss the particular point which she was trying to make in conversation with me. This interest in an expressive involvement in science blends into the third theme in Donnie's orientation, her enjoyment and interest in speaking up in class. This is explored in the discussion of Theme III in the case report.

Activity 2, "Drawing Beams and Shadows" asked students to use symbols in drawings on the worksheet in answering questions. I asked Donnie what she thought was the main purpose of the lesson, "Drawing Beams and Shadows:"

Donnie: I think it was to learn to make the certain signs we were given. I liked making the, um diagrams.
Ms. Shapiro: I like to make drawings too. Are there special reasons for making them?
Donnie: Well, it's easier to know what you're talking about because actually it's easier to do, um, like you don't um, have to do a whole bunch of things here and write a whole bunch of words. You just have to draw a diagram of what you're talking about. It's quicker and it's more interesting.
Ms. Shapiro: Do you think that scientists use symbols like this to talk about light?
Donnie: Well, I'm not sure, but I know that if I was a scientist studying light, I would.
Ms. Shapiro: Oh?
Donnie: Yeah, for the same reasons that we do it. It takes a shorter period of time and you can just scan it and it tells what you're talking about. It makes it all easier to do. It's a little hard to remember the symbols, though, but it makes it easier to do. But they probably use it in different ways.
Ms. Shapiro: Where do these worksheets come from do you think?
Donnie: Oh, Mr. Ryan makes them up. He says that he's done this unit before with his other class.

Melody, Martin and Pierre also thought that the worksheets were developed by Mr. Ryan. This could be one of the reasons that most of the children have put forward the idea that their use of a conventional symbol system in the classroom is more for the purpose of their teacher's understanding of their worksheets than to help students learn to use symbols as scientists do in the communication of information. Although Donnie does show some insight into the possibilities for symbols as conventional tools, there was no specific classroom discussion concerning the use of the symbols for communication other than for teacher correction of the worksheets. For example,

> Mr. Ryan: Let's not be lazy now. I want to see everyone using a pencil and a ruler. If you don't use a pencil and a ruler I won't accept your drawings.

Ms. Shapiro: Mr. Ryan seemed very concerned here that you use your pencils and rulers.
Donnie: Yeah, because if you don't, well, maybe he could be thinking that it's something else, like if you left out the one and forgot or just put another in instead, you might think it was a narrow beam instead of a wide beam. Like also, if you just make a little squiggly he might know that you're just fooling around and drawing things, you know, not for the lesson.

Donnie appears to have developed, on her own, the idea that scientists use convention in symbol presentation, for communication with one another, and that this is a part of the purpose of the lesson, to communicate results not only to the teacher, but to those interested in the study of light. Four of the other students in the study group told me that they believed that the purpose behind being asked to make the drawings using rulers only and using the symbol system was to communicate primarily with the teacher. Only

Mark commented that he believed that the symbols related in some way to the manner in which science information is communicated to other scientists. Mr. Ryan had not made any reference to scientists' use of symbolic representation or convention in reporting findings in science during this lesson nor during any of the following lessons, in which students were required to repeatedly communicate findings using the same symbols.

Donnie made drawings and diagrams frequently and freely, often in describing a point to me. Later in the unit, during the study of prisms and spectra, Donnie gave another insight into the special meaning which drawing had for her:

Ms. Shapiro: This is a drawing of the rainbow colors which Mr. Ryan showed you in class. (referring to a spontaneous sketch which she has made at the side of her worksheet.

Donnie: Yeah. From the poster that you put up I made this. Um, Roy G. Biv, yeah, um Red and orange, then yellow, um green and blue and idig.., well um purple he said was okay, um and violet.

Ms. Shapiro: You made a drawing while he was talking here. Why did you do that?

Donnie: Well, for one thing, I really like to draw. I just enjoy doing it. It gives me something to do while he's talking. And this makes things very clear, um cause I couldn't remember all those colors, you know. I can remember what was going on now. I have it. I can look back here when he talks about it now. So it's easier to understand. I just to draw what I'm doing, and then I have it for later.

From these examples and Donnie's own comments on the enjoyment and significance of drawing in science lessons, several unique and important meanings emerge.

Donnie uses drawing to clarify her ideas during discussion and clarification. She sees the potential for a relationship between the symbolic representation which she uses to communicate about light on her worksheets and the ways that scientists communicate their findings, though she is not sure that she is right. She says that her drawings of the color spectrum are useful reference points for looking back upon to remember ideas that she is learning and to understand them when the teacher brings them up again. And she expresses the pure enjoyment of drawing for its own sake as a way of fully participating. Clearly, throughout the study, drawing was a valuable study tool for Donnie. Although sanctioned by the teacher, interest in drawing originates with her, and it appears to be an uplifting means of involvement in her work which encourages persistence and delight in learning about light.

Theme III. Self Characterization: "I really like to speak up in class because then, well, I get a chance to listen and speak up and tell what I'm feeling."

Researcher Image/Impression: The enjoyment of putting ideas together through participation in discussion in class. The sense of making a personal contribution.

Speaking up in class also had a very special meaning for Donnie. During our videotape review of the introduction to the light unit, she referred to some comments which she made during the large group discussion:

> Mr. Ryan: We can take light and make it go in different directions. Okay. So, we've got two points of view now. We have Mark and Martin agreeing that light travels in straight lines and we have Sam thinking that light travels in circles too, like our sun.
>
> Donnie: I think it travels in a straight line because if you, like look at something, um it isn't crooked or zig-zaggy (mimes) like this, it's just straight lines (She uses her whole body to demonstrate).

Donnie: Here I was talking a little. Well, first, I had also said that you can make light go in circles, but you can make it go different ways. You can make it go zig-zag though, but I see, um no, you can't really make it go in circles. But you can have it come right over at you and then have one mirror up here and another mirror over here and then you turn them like towards each other (she draws me a diagram) like that and then the light would, um something like this, it would cross. So really you can make light go in different ways.

Ms. Shapiro: So your talking here in class helped you to understand...

Donnie: Helped me to get the idea out. Well, it helps me to understand, like if I'm wrong then I feel um well, actually that I can learn. It helps me learn. Like, if I get something wrong, if somebody tells me what the answer is, I'll remember it and learn something new.

Ms. Shapiro: So you're not afraid to be wrong

Donnie: No! (laughs) Well, I'm not always right and I don't brag about it, that I'm always right and all like that and um, a I don't get surprised when I'm wrong either, cause I know sometimes I'm wrong and sometimes I'm right. But I like to say something that I think, that I feel.

Donnie values being able to add her own ideas to class discussion, to be able to draw on her own judgement and express her opinion on the nature of phenomena. She finds it useful to talk to clarify her ideas to find out if she is "right" or "wrong." There is a pattern in her action and discussion which has implications for her way of thinking about learning here and in her way of thinking about learning science, her theory of science learning. She often expresses the idea that she herself should somehow be able to get the right answer, that she should be able to figure it out. She believes that other students are understanding while she is not. She says that she should be able to piece together ideas the ways that she thinks that others are. Though she sees others responding with correct answers, she does not see that they do not always understand the ideas fully. Mark grasps the concept of refraction because he has grasped the idea that light reflects off all objects. Even though Mark has not experienced the bouncing of light rays, he is able to believe the idea or the possibility of it happening. Donnie has not grasped this idea. Donnie's interest is in personal participation, in contributing her ideas to the conversation, and in making an effort to achieve insight through her own active participation in the science lesson experience itself. In speaking with Donnie on previous conversations concerning her ideas about the nature of light, she has made it clear that she does not believe that light rays reflect off of objects unless she can see them. Indeed, in all of the lessons in the program, the children continually refer to the visible beams of light which emanate from a light source box, and are asked to describe the manner in which these beams interact with materials. When Donnie says that "I had no idea that it was the light," it is quite understandable that from the experience which she has had in the unit that she should not make the connection between the visible beams which the children can watch and reflect using mirrors and the non-visible beams of light which are reflecting all around us. These have been referred to only briefly at the beginning of the unit, during the discussion about how people once thought objects were seen. There is no connection made in the curriculum program materials between the behavior of the light beams which the children are shown and are able to manipulate, and the light rays which are all around us invisible, yet reflecting off of the objects which we see.

In this unit, the children are asked to accept an idea which does not "make sense." The concept cannot be validated with their own experience. They cannot see the light reflecting off objects. They must accept the idea that light reflects off objects.

There are two ways that this initiation to learning science in school is confounding the student. First, in the early years and experiences of science learning, we teach children to become good observers, to trust in and rely on their own senses to understand the world. As the complexity of topics increases, we ask students to go beyond observation and to begin to learn what scientific investigations have revealed over hundreds of years of study. We begin to explain events and phenomena not in terms of what students can see for themselves, but in terms of what others have found out through their observations, observations which are based upon the use of very different equipment and ways of thinking than are available to the student. We provide further confusion in this situation by giving students hands-on activities in which an understanding of the behavior of visible light rays is shown in all activity examples while the idea of the behavior of non-visible light rays is subsequently introduced. Donnie does not make the mental leap or connection of considering the visible ray of light as behaving like invisible rays of light. In fact, she has shown on several occasions that she is not aware of the existence of invisible rays. There has been no connection made between her classroom activities and this idea. She is only very much aware that she has not been able to experience this phenomenon herself.

Donnie experiences frustration when she tries to understand the main point of the lesson through experience, but can not. She feels the responsibility for knowing and understanding as being hers completely, and because she does not understand, she feels that it is she who is failing or lacking, and has begun to conclude that there is something lacking in her own overall ability to learn science.

This sense of inadequacy becomes a theme for Donnie and appears to be a major characteristic of her developing view of herself as a science learner. The previous discussion emphasizes her view that science "isn't for me," yet she feels that it is easy for other students. Donnie is left discouraged, expressing her feelings to me in the following statement: "I never get the right answers in science."

6.7 CASE REPORT II: MARK

6.7.1 Some Initial Observations and Impressions

Mr. Ryan described Mark as "an average to above average student, a very cooperative person, but still quite young in some ways." In fact, Mark at age 10, was the youngest person in his class which was composed largely of largely of eleven and twelve year olds. I made some initial observations and reflections in my journal during the first two weeks of my stay:

> Mark listens intently to Mr. Ryan and other members of the class during the large group discussion. During a discussion on the development of "evaluative" questions in the reading period, Mark's eyes are almost constantly fixed on the teacher. He frequently tips back on his chair in a relaxed fashion. Mark mouths the answers to questions posed by Mr. Ryan in what seems to be a confident and firm response. When Mark raises his hand to answer a question, he raises it high and waves exuberantly. He seems to be enjoying this discussion on the nature of light immensely.
>
> On the playground: Melody and Daphne are walking along with me, one holding each arm. I have been watching Mark play. He is crying after an incident in which he was unjustly accused by the playground supervisor, (who doesn't know him) of deliberately sliding into another student, knocking her down. For 2-3 minutes he appears to be extremely embarrassed and frustrated by the ordeal. He looks my way, but does not ask me to intervene. Then suddenly, Mark returns to play ice tag with three of his classmates, and seems to have forgotten all about the accusation.
>
> Though he is physically much smaller than the other children, Mark is quick, agile and an effective competitor on the playground. By

> virture of his speed and clever moves, he is a challenging and popular playmate.

6.7.2 PART I: Thoughts and Feelings About Learning School Science

Initial Conversations

Mark and I reviewed the first survey which I had given the students. I asked him to comment on his general feelings towards studying science in school:

> I find science pretty easy most of the time. I get things mostly that sometimes the other kids don't, or er,um, have sort of trouble with.

On several other occasions during my stay in the classroom, Mark reiterated that he had a sense of himself as a very successful science learner. He believed that he had recognized an ability to figure things out quickly. He added that because of this ability in Science class he often had more free time and the opportunity to do extra science experiments on his own:

> In Science, me and Willis Simpson are always finished early, so we like to do experiments on our own. So, like test out our own ideas and stuff, and try things that we want to.

In fact, the theme of enjoyment of working on his own became the first theme in his snapshot portrayal which is presented in Part III.

When asked, "How do you feel about learning science, Mark checked the category marked, "I _really_ like it!"

He added an extra embellishment to emphasize his "x". He wrote that he felt this way "Because I think science is chalinging (sic)." Mark answered the question, "What do you like most about studying science?" with, "I just really like finding out new things."

Mark stated that he did not study science outside of school and that science outside of school "is not as important as the science we learn in school." He told me in conversation:

> I don't really _study_ science at home, I have fun with it and things and mostly what I do in science at home is watch programs and read a few science books. But I don't really _study_ it at all. I just sort of enjoy it at home and outside and things.

Mark's Ideas About Ways of Learning Science

Mark's classification of Typical Science Activities, grouped by preference, appeared as follows:

_A_ "The activities that you like the very best"

- Do experiments on my own
- Do experiments with other kids
- Go on field trips
- Make science diagrams and drawings
- Do science fair projects

_B_ "The activities that you think are just "ok"

- Watch demonstrations by my teacher
- Do science worksheets
- Read library books on science topics
- Talk about science ideas with other people

C "The activities that you don't like"

Read the textbook
Write reports on science topics

I showed Mark the way that his activities grouped. He pointed to the last group and remarked:

> Well, I do like reading and stuff. It's not that I don't like to read. But I really prefer to find things out by myself, like when I do the experiments about them myself. And yeah, well, science reports, yeah, I don't like them. Well, like sort of when we get to pick the topic like that we want to. We did that last year. And um, but usually we don't do that and it's really quite boring so I guess that one's in the right place there because I like to do the experiments more.

Mark had defined science on the survey sheet as "mysery and fun" (in conversation he stated that the former word is mystery). He describes science metaphorically, saying, "Science is like going on a different kind of adventcher (sic)." You're trying to solve a puzzle and you have all of these steps along the way." I asked Mark why he believed that science is studied in the elementary school. He answered without hesitating:

> So that people will be able to know about how things really are and how they work so that they can do things like go to the moon if they want to, or whatever, and so that they can understand about um, like the beginnings of the world and how the world is, like, what it looks like from outer space and all."

In these comments whe can see that Mark holds two ideas about the benefits of learning science in school. One benefit is that science allows us to answer questions which are of interest to us. The other benefit which he believes is to be gained is insight for the purpose of applying technical knowledge to allow us to accomplish a task or goal.

Overall, Mark regards the learning of science in school as a very positive experience. He sees himself as a competent and successful learner of science. He considers science to be a very easy subject to learn, even though he tells me that he realizes that other students sometimes struggle with activities and ideas which he quickly grasps. Mark expresses a definite confidence in his ability to perform in Science class and exudes obvious enjoyment when recalling past school experiences in Science. He regards the activities of learning science in school as somehow more important than the science activities that he participates in outside of school. Outside of the classroom Mark says that he participates in such activities as "watching television programs and reading books," and "wondering about my own questions." As an example of the latter, Mark attempted to share with me some of his thinking about natural phenomena:

> Sometimes at night I look up at the stars and things. I wonder what made them, and what it's like on other planets. And I wonder if, like if there's an end to the universe and stuff. Or I try to figure out what makes a star sort of pulse like it does.

I asked Mark if his father or mother were interested in science and perhaps encouraged his pursuit of science. He said no, but that "I like to talk over my ideas about things with my dad." Mark's father, a carpet layer, and his mother a career homemaker, had no special interest or expertise in science, but Mark stated that they encouraged him to talk about and learn about what he found interesting. He commented that they had bought him some National Geographic books on the universe for his birthday.

6.7.3 PART II: Summary of Mark's Ideas and Feelings About Light Prior to the Light Unit

Introduction

Mark's views about the nature of light, prior to the study of the topic, are presented in a summary below.

What is Light?

> Light is, ah, well, I dont't know what it *is*, like, but, it's, um, it travels in outer space and from the sun to the earth. I guess it comes from the sun mostly. And we have electricity. That can be put in the form of light also.

Comment: Mark indicates that he realizes that he is able to understand the fundamental nature of light. Other children in the study seemed confused about what actually was meant by the question, as light is more commonly associated with the personal experience of lightness or darkness.

6.7.3 Where is the Light in the Room?

> Overhead in the lights. There's quite a lot coming in from the window, and some is coming in there from the hallway. (we are in a glass enclosed interview room and can see the hallway)

Comment: Mark associates light both with its source ("the lights") and with beams which are visible.

Association of Light Phenomenena With Everyday Objects

Mark's ideas about association of light with everyday objects before the study of the topic are presented in Table 6-5.

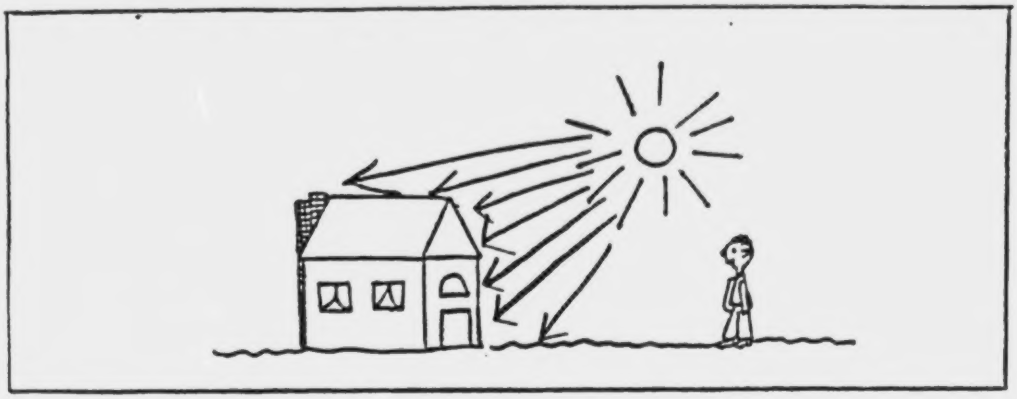
Comment: Mark is one of the few students who has checked magnifiying glass and plants as associated with light. He tells me that he has directed sun light rays onto paper, and that this is how he associated light beams with the magnifying glass. He states that he realizes that plants require light in order to grow. Only 1 other student in the class made this association.

Table 6-5.

MARK'S ASSOCIATION OF LIGHT WITH EVERDAY OBJECTS

	Number of Students Checking N=33	Mark's Response
1. ELECTRICITY	28	+
2. CAMERA	28	+
3. TELEVISION	27	+
4. LASER	27	+
5. EYES	25	+
6. RAINBOW	24	+
7. MIRROR	23	0
8. STARS	21	+
9. X-RAY MACHINE	19	+
10. MOVIES	19	+
11. FIREFLIES	19	+
12. PLANTS	12	0
13. MICROSCOPE	6	0
14. TELESCOPE	6	+
15. ROCKS	3	0
16. BIRDS	2	0
17. MAGNIFYING GLASS	2	0
18. PENCIL	1	0
19. CANDY	1	0
20. CLOTHING	1	0

How Does Light Allow Us to See Objects?



Mark: Light is falling onto the house shown by these rays here. The boy then can see the house.

Figure 6-7. How Does Light Allow Us to See Objects? Mark's Response

Comment: There is no indication in his drawing nor in our discussion at this point that Mark understands the scientist's conception that light beams reflect off objects into the eyes of the person standing nearby.

What Happens When Visible Beams of Light Travel To An Object?

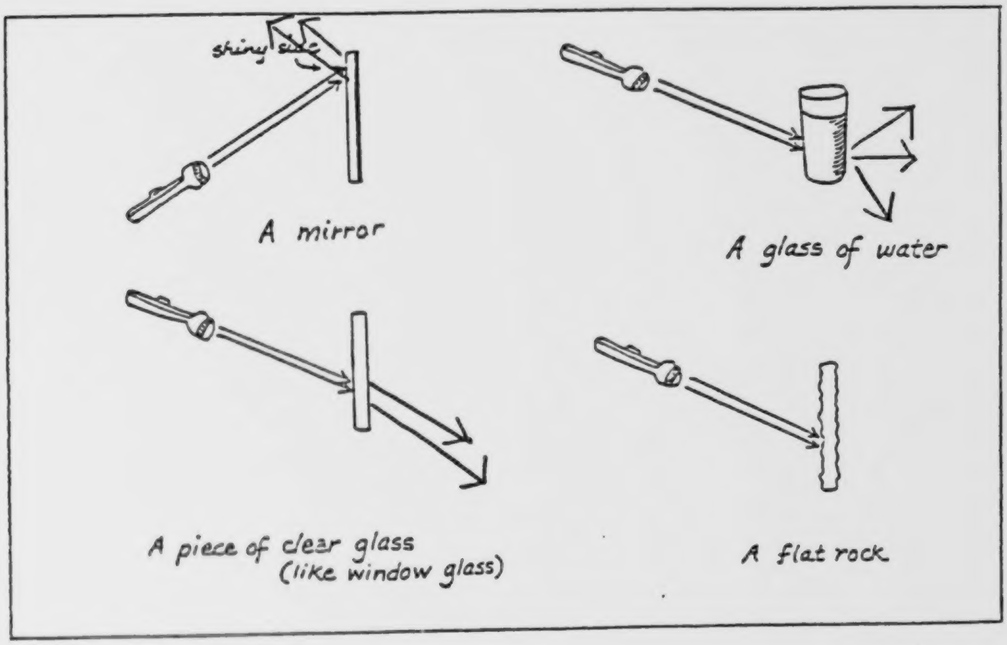

shiny side
A mirror
A glass of water
A piece of clear glass
(like window glass)
A flat rock

Figure 6-8. What Happens When Visible Beams of Light Travel To An Object? Mark's Response.

Comment: Mark tells me that in the final example, when light beams strike the flat rock, that they "stop because the rock stops them."

How Do We See Color?

> I think that there are special things, like um, receptors in our eyes that let us see the colors in things. We studied the eye a lot last year. There are cones and rods and those are in the back of the eye.

Feelings Associated With Light and the Study of the Topic, Light

> Um, oh, I don't know. Um, I look at the stars and I like to wonder sometimes about the universe and all. Sometimes, um, I like to watch the light on water. The light on the snow out there is really pretty. But sometimes it's just too bright out there!
>
> I'm really interested in studying about light. We've been doing a lot with Batteries and Bulbs and that's fun. And so, I'm looking forward to it. We did a little about light when I was, I think in grade two. But I think we'll do a lot more with it with Mr. Ryan.

Comment: Mark appears genuinely interested in the study of the subject light, itself. Only one other student in the study group, Martin indicated that the topic was of real interest.

6.7.4 PART III: Personal Orientation to Science Learning: Revisiting the Study With Personal Constructs and Emerging Themes - Paradigmatic Instances of Thought and Action

Mark's Personal Constructs

Mark's personal constructs and ratings of science experiences while while learning about the topic, light, are presented in the Repertory Grid Chart, Table 6-6. His comments on the factor groupings of the constructs are shown in Table 6-7.

Emerging Themes In Mark's Personal Orientation To Science Learning

Three themes were used as a framework for development and presentation of Mark's personal orientation to science learning. These emerge from my observations in the classroom, through the personal construct charts and through ongoing discussion with Mark. The themes are used to revisit the study and develop a snapshot portrayal of Mark's personal orientation to science learning. The themes are developed through the presentation of examples of thought and action or "paradigmatic instances" which illustrate Mark's personal anticipations and expectations for science learning, and can be seen to guide his interaction in the science classroom. All of Mark's individual themes can be seen in a number of learning sequences which occurred during the unit.

Table 6-6.

MARK'S PERSONAL CONSTRUCTS

1. Doing things that you really like to do, really enjoy.	5135122225432535542253252353234523142	1. Somebody tells you what to do.
2. Doing things for yourself.	5225223215433525251353252354334424141	2. Somebody else tells you what should happen.
3. Hearing about things that make you wonder.	2234433221132251334233333342132354241	3. Hearing things, but you aren't really listening.
4. Experimenting with other people.	2432223532242332325143431432121553541	4. Doing it on your own, reading more.
5. Doing what you're supposed to, working to find an answer to a question.	3222122224323253213223333542131354141	5. Not doing what you're supposed to, so you won't be able to answer.
6. Getting help to find the right answer.	1133333225131251313313312441231555152	6. Not getting the idea.
7. Sure of yourself.	3132333215431555222333252354323554153	7. Confused.
8. Just telling and talking about ideas in class.	4314222224242223352145432332222513433	8. Ideas are being corrected as right or wrong.
9. Helping someone come up with something different from what is on the overhead.	5424223234433335252245342423233424243	9. Helping someone get exactly what is there.
10. Work on my own.	3223222225423555333332153454323555152	10. Needing help/asking for help.
11. Experimenting with things.	5335112115444445351353342335132542132	11. Just listening to what Mr. Don says.
12. Copying down exactly what's there on the overhead.	2231434442233442415431414123333242415	12. Coming up with something different.
13. Talking about things.	4424332224442335253155352324222413351	13. Just jotting down the information.
14. Knowing what's going on.	2232222215421555212232151554223544143	14. Don't know what's going on.
15. Finding out what science tells us.	1431123323214351411511414332444433132	15. Telling what we think.

Table 6-7.

MARK'S STATEMENT GROUPS

Group 1

Doing things that your really like to do, really enjoy.
Doing things for yourself.
Just telling and talking about ideas in class.
Helping someone come up with something differeent from what is on the overhead.
Experimenting with things.
Coming up with something different.
Talking about things.

Mark's Statement: Here I can do something that I really like to do and I get to experiment and come up with different ideas. I really like to do that. It's fun.

Group 2

Doing things that your really like to do, really enjoy.
Doing things for yourself.
Sure of yourself.
Work on my own.
Knowing what's going on.

Mark's Statement: Here I'm getting it all and I'm really sure of myself.

Group 3

Hearing about things that make you wonder.
Experimenting with other people.
Doing what you're supposed to. Working to find an answer to a question.
Getting help to get the right answer.

Mark's Statement: Having a real challenge and working hard to come up with the answer. Sometimes I get help from the other kids and sometimes from Mr. Ryan.

Group 4

Finding out what science tells us.

Mark's Statement: Finding out what science tells us!

Theme I. Self Characterization: "I really like to do experiments and things, things that I'm doing for myself. I really enjoy doing things myself and coming up with ideas that are different than just what's on the overhead projector."

Researcher Image/Impression: Self-motivation. Enjoys finding things out for himself.

In our conversations and reflections on the lessons, Mark spoke often about the enjoyment of experimenting with ideas and materials on his own. I observed several examples where Mark worked extensively and creatively on his own with materials, where he was in charge, autonomous, even to the point where other students were following his example, or where he was able to help other people to understand. But Mark sees himself as receiving real help only from his teacher, Mr. Ryan. He comments that Mr. Ryan is his most valuable source of building new ideas and insights in Science class. He accepts Mr. Ryan's statements as not only coming from a trustworthy authority, but Mr. Ryan is speaking about phenomena and events which are truly of interest to Mark, which he says "sometimes really make you wonder." In fact Mark provides, through his personal constructs, a distinction between hearing about things that make you wonder and those that you do not really listen to:

3. Hearing about things make you wonder.	3. Hearing things, but you aren't really listening.

He says that the material which he really listens to is the "stuff that's really interesting, that I want to know about. The other stuff I just usually don't pay attention to." Mark makes it clear that he prefers to gain insight through actually *doing* science activities for himself, yet he values information coming from the teacher, whom he considers to be his key authority, and his most important source of information.

Theme II. *Self Characterization*: "I like to hear what *science* has to tell us."

Researcher Image/Impression: Values science knowledge as tentative explanation.

Mark has been the only person in the study group who has made specific reference to his lessons and activities as activities and experiences by which we "find out what *science* tells us." In the elicitation of personal constructs, he contrasts "Hearing what *science* has to tell us," with "Telling what *we* think." He does not equate the two, but sees a connection between his own experience of Science in the classroom and his experience of hearing the story of science. Mark is open to acceptance of an idea even though he may not be able to 'see it with his own eyes.' Mark simultaneously held two theories of science knowledge which are in contrast to one another, but which are both useful to him in learning science. In the first case, Mark is interested in learning the *story* of science, the ideas that scientists have come up with at this point in time and how they have shared them with us. This view conceives of science as telling us what is out there, and suggests that truth is waiting and needs only to be found. This became clearer during our video recall sessions. Mark referred to doing science in the following way: "It's like you're putting together the pieces of a mystery." In fact, Mark is a very serious reader of mysteries. Students had recorded the books read throughout the year, and, in fact, Mark listed 14 out of his 25 books read as mysteries. Mark spoke of doing science as an effort to find out "about the way things really are." He simultaneously likened learning science to a puzzle to be put together to discover an answer, and suggests that "most things in science are right," he simultaneously holds the view that science knowledge is tentative and changing. In one of our videotape conversations, I asked Mark if he had some insight into how it might be that he was able to grasp ideas that others seemed to have so much trouble with.

Mark: Most science things are right.
Ms. Shapiro: Most science things are right?
Mark: Yeah.
Ms. Shapiro: Can you tell me what you mean by right?
Mark: Mmmm. Well, when you say, like, people used to say that the earth was flat, and it's really round. So science is the right ideas about things. Some of the ideas in the future might change though.
Ms. Shapiro: I see-
Mark: And like Mr. Ryan said, people used to think that there was something that came from your eye to the object and that let you see the object. But the right idea is that the light reflects on he object and goes into your eye, like I said before. So that

helps.
Ms. Shapiro: How do you know that that is true?
Mark: Because Mr. Ryan said so. (Laughs)
Ms. Shapiro: How do you know that Mr. Ryan's answer is the correct one?
Mark: Well, he's taken light in college and all and the tells us what he knows from that.

In addition to accepting the current ideas of scientists, Mark has an appreciation of the tentative, changing nature of the processes by which ideas are acquired in science. As Mark has said previously, he regards Mr. Ryan as his most valuable source of help and direction in the study of the topic, light. Valuing the tentative nature of science knowledge also implies for Mark a special relationship with Mr. Ryan, who he sees as his primary conveyor of special insights. However, acceptance of Mr. Ryan's authority does not keep him from questioning a viewpoint, which has been presented in class or which deviates from his own sense perceptions.

As an example, during the review of the videotaped lesson on color, Mark commented on his understanding of Mr. Ryan's discussion of how we are able to see color.

Mark: It was always known that color was, like seen by light and all. Mr. Ryan is saying that people used to think something different. They used to think that it was _in_ stuff, like _in_ the thing. But Mr. Ryan was saying that it's reflected _off_ of things and we see the colors by the way it reflects off.
Ms. Shapiro: Do you think that is true?
Mark: Yeah. Oh, yeah. Except um, here, um I didn't get with, with the colored light and all that we were doing. There's color here that we were seeing. I'm not sure what that was supposed to be. You know, when

we were looking here, and we couldn't figure out what it was and we asked you and you even said that it was sort of pinkish too?

Ms. Shapiro: Yes, the mixing of colored light.

During this activity, each group produced colored light by shining light from the light source through colored plastic. The resulting colored beams directed and redirected so that they were mixed with one another. The children were asked to describe the newly formed color. Having some differences of opinion, several groups had asked if I would come over and tell what I saw as the new color. Each group had plastic of slightly differing shades of color, therefore each group had a slightly different result. In each case, however, the color resulting when combined on the white screen used, was a pale rose or pink. The "correct" answer, however was not rose or pink, but was white. Every group had difficulty accepting this answer. No one had seen a true white in the combination, yet "white" was the only answer accepted as the correct response to the question.

Though confusion reigned on this problem in the classroom, and was expressed among the students in their work groups throughout the activity period, when the time came to discuss their results publicly, no child protested, challenged, nor even expressed puzzlement about the contradiction between what students had seen for themselves and what they were told that they were supposed to have seen. They quietly corrected their worksheets, but many with confused and puzzled looks on their faces. During the video recall sessions on this activity, all of the students in the study group expressed frustration with the experience and questioned me about the light, which they saw as one color and were asked to accept as another color.

I asked Mark what he thought of the suggestion by Mr. Ryan that students should be seeing one color when, so many, in fact, saw something else.

Mark: Well, I didn't see white, either. You didn't either did you?
Ms. Shapiro: No.
Mark: So, I thought maybe Mr. Ryan made a mistake at at first. But he said he saw white and that that's what it's supposed to be. So I guess I thought maybe that's what it's supposed to be even though it doesn't look that way, that's what it should be, because maybe the light here isn't the best. But I don't know, because it, if you looked at it a certain way, I could see how somebody might say it was white.

Here again, Mark's orientation to being open to "what science has to tell us," allows him to consider the possibile truth of that which he cannot verify with his own eyes, yet he does not deny that he had difficulty with what should have been seen. In reviewing Mark's personal orientation to science learning, we can see that his very positive feelings about himself as a science learner are continually reinforced by his having a great deal of success in the subject.

Mark's interest in the ways that we learn from science itself, shows a fundamental uniqueness in his approach to science learning and that of all of the other children in the study group. In contrast to Donnie, Mark does not take the complete responsibility for working the answers out upon himself. He is open to changing his ideas without need for direct personal evidence and he is interested in knowing what have been the trials and errors of past researchers. Mark has, then a sense of the history of science, often seen in his comments on Mr. Ryan's discussions, as he recalls how "people used to think..." when referring to the nature of light and color. In this way, Mark places himself in intellectual partnership with the past, learning from the work of others while at the same time constantly seeking personal autonomy, he likes to then test ideas out for himself, confirming for himself. Mark is able to listen to and comment on the story of science. His interest and personal orientation to science is directed towards knowing what this science story has to offer so that he may better understand the experiences he is having with materials in the classroom. Mark's awareness of the nature of knowledge growth in science is coupled with a delight in active participation in the ideas and materials that are being presented in science lessons. He attempts to relate and connect both his experience and the story of science.

Though Mark also asks the deeper questions of science, such as, "Is there an end to the universe? How does light travel from other planets? Is there life on other planets?," he seems less deeply disturbed than Donnie when he does not have all of the answers or is not immediately able to solve all of the questions effectively.

Mark's approach to learning science during the unit shows important areas of significant constrast with the other students' experience, both in terms of his grasp of ideas, of his repertory grid themes and self characterization of himself as science learner. Most notably, Mark was able to quickly grasp the single concept which is most basic to the further development of ideas in the unit, that light rays reflect off all objects. Many further ideas in the unit were built upon an understanding of how reflected light enables vision, a concept which students of all ages have difficulty grasping. Light rays, continually reflecting from the objects around us enable us to see objects. Not only was Mark able to grasp this idea early in the presentation of the unit, but he was able to use this fact to explain many other types of light phenomena.

This aspect of Mark's personal orientation appears to be based upon an interest in and openness to acceptance of new ideas which he may not be able to verify for himself. It appears that even though this new information presented in the Science class may often conflict with information which he is able to validate with his own senses, Mark is able to believe and to completely accept new ideas because science has established these ideas and they are conveyed via the the authority of Mr. Ryan. This interest in what science has to reveal is key in Theme II of Mark's orientation to science learning. This openness and willingness to re-orientate his views exemplifies George Kelly's principle of Permeability. This principle emphasizes the individual's capacity for change. The individual's personal constructs are the reference or starting points for novel and new subordinate constructions which form what Kelly refers to as the whole person construct system (Kelly 1955).

Mark's personal orientation to learning science not only included an openness to change, but he also approached the study with an interest in making connections between his own experiences and the ideas which the teacher was presenting during the unit. During one particular classroom visit, I recorded an example of Mark's skill in making connections between his own experience and between the ideas presented during the unit, which is the first example described in Theme II. This example has already been referred to in Donnie's case report as it had was an important example affecting her experience of science learning as well. This incident provides an example which demonstrates all three of the themes of Mark's personal orientation. As an example of Theme I, we see that Mark is working very much of the time on his own. The second theme is demonstrated through this example of his unshakable self-confidence in his own science learning ability. And finally, Mark's intense interest in what science has to tell us is portrayed in this example which also relates to the third theme of Mark's story.

Theme III: Self Characterization: "I'm really getting all of it and I feel sure of myself and what I'm learning. And I'm really enjoying myself."

Researcher Image/Impression: Assured self-confidence as a science learner.

Lesson 9, "So Deceiving," proved to be one of the most enjoyable, but one of the most difficult lessons of the unit. As mentioned, it has been useful in the characterization of Donnie's personal orientation themes, as it had an impact upon all students in the classroom. In this activity, the children were to observe two instances of refraction in the lesson. In the first, a coin was placed in an empty saucer. The students were to then move slowly back from their tables, crouch down, all the while looking at the coin, and to stop at the point where they could no longer see the coin. One group member then slowly poured water onto the saucer. As this was done, the 'non-visible' coin suddenly became visible to the crouching observers. In the second activity, students were directed to a pencil in a beaker half full of water. They observed the pencil in the beaker, then explained why the pencil appeared to be broken when viewed from the side of the beaker.

I sat near Mark's group during this activity session. In the first example, I watched as Mark observed the coin slowly appearing. Suddenly he jumped up, excitedly telling the others:

> I know! I know what's making it do that! It's the light rays. The water's bending them!"

The other group members at first appeared perplexed by Mark's statement. They ignored him and continued to look at the beaker from different angles. Still excited about his insight, Mark tried to re-explain his idea to the group. This time, his activity group listened, but once again, did not appear to understand his explanation. They returned to talk among themselves about what they thought was happening to make the coin appear to float to the surface.

Mark walked over to Donnie and Carey's table, pointed to the saucer which was also filled with coin and water, and proclaimed to Carey, "I know why it's doing that!" Carey did not ask Mark for his explanation. She seemed intent on finding a solution of her own. Undaunted, Mark emptied his saucer into the nearby sink, then literally hopped and skipped back around the room to his desk.

The Making of An Insight

In this sequence, Mark had made some very important connections between and among the ideas and experiences presented to the class to this point in time. Mark obviously recalled and used information which Mr. Ryan had presented in a lecture on the first day of the unit. He was making connections among these ideas to his most recent classroom experience to explain the changes in the appearance of the objects in this activity. This lesson on refraction occurred at the end of the school day. Because of his extraordinary understanding compared to his fellow classmates during this session, I asked Mark if he would mind staying after school with me to discuss the science lesson. Mr. Don had informed Mark at the end of the lesson that his explanation was correct, and he was still quite excited about his discovery of this insight. He seemed pleased to discuss it further.

Ms. Shapiro: I'm very interested in your telling me more about the activities which you have been involved with today. You know from our video sessions that I'm trying to understand how kids are learning ideas like the ones presented here. I was with your group when you were looking at the saucer of water today, I was watching when you saw the coin. I heard you say, all of a sudden, as you were looking at the coin, "It's the reflected light!" I wondered if that was an idea which just came to you all of a sudden or, can you tell me what it was like at that time, what happened for you there?

Mark: Well, hmmm. I guess it's that I just like Science a whole lot, and I just think that it was because of being, um, of remembering from before.

Ms. Shapiro: I see. You know, it looked like the ideas just seemed to came together for you all of a sudden. But you say you remembered from before.

Mark: Well, yes, it was sort of all of a sudden. Well, I knew the, um, pretty much the ideas what were going on before, because, he had told us, um, Mr. Ryan had told us lots of things, and then we did a few experiments and that made things a lot clearer.

Ms. Shapiro: Oh, I see. Can you tell me what you remember and which experiments you found helpful?

Mark: Well, um I guess mostly when he told us about the light, how people used to see things, like they thought they saw things coming from your eye it, or think it was coming from your eye. But we know it doesn't now. And the one, well I guess, with the beaker and the light bending through the water, that one was the one that helped me the most. That showed me how the light bends and all when it goes through the beaker and water, you know, from the light source?

Ms. Shapiro: Yes, I remember that. When you started to tell the others in your group that it was the light that was reflecting off, how did they react?

Mark: Oh, yeah. They acted sort of surprised and stuff. At first they didn't understand it and but so then I told them again. They thought that the penny floated up to the top or something. I told them that the light was doing it. It was the reflected light.

Ms. Shapiro: Yes, when the class discussion took place later, and when Mr. D. was asking, "What was happening, why do we see the penny, why do you see the coin there and why does the pencil look like that?." Everyone gave different answers.

Mark: Yeah, some people thought it was the water, some people thought it was the glass, some the glass and some the curve in the glass.

Ms. Shapiro: I wondered why in the class discussion that you waited until the end of the discussion to give your answer.

Mark: Well, I was, sort of trying to figure out what um, if I was right.

Ms. Shapiro: So, you weren't quite certain whether or not you were right.

Mark: No. Well, I guess. But I just waited.

Ms. Shapiro: So you waited. But then when you finally did give your answer, were you sure you were right then?

Mark: No. (Laughs) Not really at all. But see, I was going a way back in the beginning and putting things I learned together, and I didn't um, I thought I was right, but, I coulda been wrong, too. I guess, um it just seemed to fit all together.

Ms. Shapiro: Was there a particular part of this activity that you found that made it most clear to you?

Mark: Well, like I said, when I was little, and even now, really, um I used to always have a really good memory and stuff, so that helps me a lot to remember things.

Ms. Shapiro: Were there parts of the lesson itself that seemed to help you to make the connection to this important idea that explained things for you?

Mark: Well, not here, because we were just putting together here all the things we learned from before.

Though several children in the group had spoken of previous or of current science learning experiences as being difficult or frustrating, Mark consistently spoke of his science learning experiences as being very positive. He commented on positive aspects of both his past experiences and of this present experiences in learning science. What was particularly noteworthy was Mark's complete and happy involvement in the lessons. As he commented:

> I've always liked Science. Always a lot. And I usually..., I find it very easy. In the last thing we did, the batteries and bulbs, I got things all finished early, because all you had to do was light the bulb. And that was easy, so, I went on to do some other things. And sometimes I can help the other kids with what they're doing.

These comments were particularly noteworthy because of the number of students who complained about the difficulty of the last unit, "Batteries and Bulbs." In fact, all of the other children in the study group commented spontaneously on the frustration and difficulty which they experienced with the previous unit, "Batteries and Bulbs." Throughout the light unit, Mark's continual expression of enjoyment in the challenge of the science learning experience was apparent.

The Impact of Mark's Ideas Upon the Rest of the Class

Clarification of personal orientation to science learning shows how valuable Mark's particular and unique approach to science learning has been in serving him in the understanding of ideas in science class. But the effect of Mark upon the larger classroom system has also been noteworthy. Here, he has, in holding and expressing his ideas, incited a small flurry of interest and discussion in the classroom. Several of the children report that they listened much more carefully to Mark's comments because they found them confusing, troubling or puzzling. All of the children in the study group commented that the teacher's manner towards Mark indicated that he had achieved the correct answer to the question which had asked for the explanation of refraction. They suggested that because the teacher wrote Mark's statement on the overhead projector, that this indicated beyond doubt that the answer which he had given was the correct one.

Several members of the class commented that hearing and contemplating what Mark had to say about the phenomenon was something that changed their thinking about the ideas which they were learning. The interest which the children had in another student's ideas seemed a great potential opportunity for a change in the thinking of the students in the class. Unfortunately, Mr. Ryan was not aware that the idea was, in fact, difficult for almost every student in the classroom. But Mr. Ryan did not pursue the idea. He told me in conversation that he had not realized that even after reiterating the correct idea that most of the students did not understand it. It is true that some members of the class did spontaneously reorganize and begin to think differently about the phenomena. Others, though slower to change their thought, might have done so with further encouragement and reinforcement, had the situation been recognized as an opportunity to maximize the benefits of the disruptive impact of Mark's radical idea.

Prigogine and Stengers (1984) have created the term "dissipative structure" to describe the fluctuations and perturbations which occur within interacting systems, such as the social environment of the classroom described here, eventually leading to reorganization and change within that system. "Dissipative structure" has been a useful metaphor for understanding how interactions occur within human groups to bring about change in individuals' and in groups' thinking and learning. Mark's case and the subsequent effect of his insight on the class is an excellent example of rapid interaction and change in the classroom from one set of ideas to another--a dissipative structure. Because of the intensity of interactions and interest which Mark's new and unusual ideas generated in the class, there was greater attentiveness to the problem, and a critical period during which students were carefully considering the new ideas presented to them.

Another aspect of Mark's insight on the rest of the class was seen throughout the study in the effect of special friends upon one another as caring listeners and persons interested in working ideas out together. When I first began to become acquainted with Mark, I noticed that he would often come over to Donnie's table to talk with Donnie's work partner, Carey. Mark frequently came to share an idea with Carey or to see how she was progressing on a task. Though the other children teased Mark about "having a crush" on Carey, their sharing of ideas and insights seemed to be very important to their enthusiasm for their science work and in the development of ideas. Both Mark and Carey were respected and admired by their classmates for their academic abilities. In fact, Mark and Carey were often approached by other students who sought help or guidance from them. Mark and Carey also valued and admired one another's academic ability. This was also particularly apparent during their sharing of insights during the mathematics period. Though the influence of Carey on Mark's classroom life did not emerge as a theme in the snapshot portrayal, it is significant in Mark's story as he is an individual who is often ahead of other students in his insights and thinking in science. Throughout the study, as the examples show, Mark's ideas are often so advanced that they are not heard or accepted when he shares them with other students in the class. This does not seem to discourage or thwart Mark's continuing insights, and as can be seen in his personal construct groupings and statements, he often prefers to work on his own to come up with something different than the rest of the students. Having a special friend in the classroom with whom he can share these insights and findings is not a need which he has, but has served as a means for him to discuss and develop his ideas.

6.8 CASE REPORT III: MARTIN

6.8.1 Some Initial Observations and Impressions

Martin is one of two students in the study group, who, along with Melody, is also part of a group of six class members who receive remedial instruction in reading and mathematics. Their resource teacher, Mrs. Lauren, comes into the classroom three afternoons a week to provide special help with these subject areas. Martin has unusual difficulty with reading. According to Mrs. Lauren, district-wide testing shows that Martin reads at a grade two level.

Early in our conversations, Martin told me that for the previous five years he and his brother attended a private religious school. His parents were unhappy with his progress there, and enrolled him in a public school this year, hoping to assure adequate preparation for junior high school. Martin volunteered this informtion during our first conversations and explained further:

Martin: At the beginning of the year they put me in grade six, but they found that I had a little um, they found that I couldn't manage it. They saw that I was having a little trouble, so they put me back in grade five. Like, that wasn't too great, you know, at first. Like, how would you, um how would you feel if they, um if that happened to you?

Ms. Shapiro: Well, I guess at first I'd wonder what was happening to me and how the other kids would respond to me.

Martin: Yeah. Right. Right. So I just let it play, let it play so I could see what would happen, right? And just let it play, let it play. But the very first day some

> kids were trying to bug me. I grabbed them and just, you know, started to whale on them, (laughs) and then after that you know, a lot of people stayed away. Now, I don't care if they call me names now. I mean, they're only joking now...(pause). See, like, here in that video, Steve and me, Steve is writing on my paper, Martin the Great. See, like I'm the big shot of the class now. Like, most kids, like, they play with me, like some of the kids, right right? Like they're sort of scared of me.

6.8.2 PART I: Martin's Thoughts and Feelings About Learning School Science

The themes of Martin's personal orientation to science study interweave and interplay to such an extent that they are difficult to separate. This seems partly due to the dominating influence of Martin's difficulties with academic work, with his initial humiliation at being placed back a year in his new school, an an apparent need to 'prove himself' to the other children and to his teacher. Science class is an arena in which Martin has apparently experienced great success. Here he is able to relax, to "really enjoy myself." In Science he has been able to demonstrate some skill to the other children and to Mr. Ryan.

Martin checked the most positive response possible in answer to the question, "How do you feel about learning science?" When asked in the survey why he felt this way, and wrote:

> I fell i Lern thing and i Lick to experiment a loT.

[I feel I learn things and I like to experiment a lot.]

Martin vigorously told me that there was nothing that he did not like about science study. He finished the sentence "Studying science is like..." with "have fun and Lring will you are haveing fun" (sic). Martin tells me that "science is one of my best subjects. I like it as much as gym." It is clear that an important aspect of the special meaning of science learning for Martin is in the enormous pleasure which he derives through the physical manipulation of and involvement with objects. In our conversations, and through observing Martin, he seems deeply motivated to finding out how things work.

6.8.3 Part II: Summary of Martin's Ideas And Feelings About Light Prior to the Light Unit

Introduction

Martin's ideas and feelings about light prior to the study are summarized below.

What is Light?

> Light is, um, well made by electricity. So whatever is in, or goes into electricity is what it must be made of. It comes from, the sun and stuff, and flashlights.

Where is the Light?

> The light in this room? It's everywhere. It's all around. Especially by the light bulbs, and well in this room it's mainly there. How are those, um like these lights are different than the light bulbs like the kind that we have at home, like the kind we opened up last year. So it could be sort different like.

Association of Light Phenomena With Everyday Objects

Mark's ideas about association of light with everyday objects before the study of the topic are presented in Table 6-5.

Comment: Martin associates the camera with light because of the flash of light which occurs when a picture is taken. He associates the microscope with light because he recalls using a microscope with a small light source attachment, and he told me that he likes to set paper on fire by directing rays of light through a magnifier and that is why he associates light with the magnifier.

Table 6-5.

MARTIN'S ASSOCIATION OF LIGHT WITH EVERYDAY OBJECTS

		Number of Students Checking N=33	Martin's Response
1.	ELECTRICITY	28	+
2.	CAMERA	28	+
3.	TELEVISION	27	+
4.	LASER	27	+
5.	EYES	25	0
6.	RAINBOW	24	0
7.	MIRROR	23	0
8.	STARS	21	+
9.	X-RAY MACHINE	19	+
10.	MOVIES	19	0
11.	FIREFLIES	19	0
12.	PLANTS	12	0
13.	MICROSCOPE	6	0
14.	TELESCOPE	6	0
15.	ROCKS	3	0
16.	BIRDS	2	0
17.	MAGNIFYING GLASS	2	+
18.	PENCIL	1	0
19.	CANDY	1	0
20.	CLOTHING	1	0

How Does Light Allow Us to See Objects?

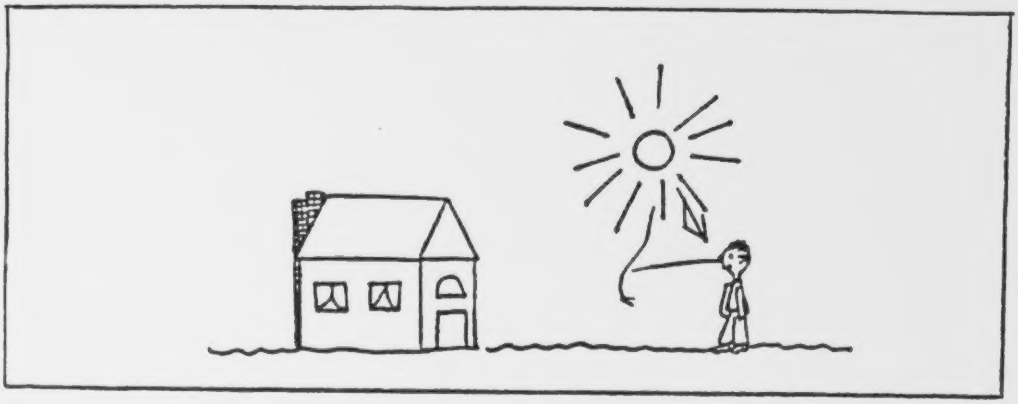


Figure 6-9. How Does Light Allow Us to See Objects?

Martin: The light shines down on the boy and so he uses it to see the house.

Comment: Martin does not comment on the light reflecting from the house, but his idea that the boy is somehow using the light may be helpful in leading him to a clearer understanding of the scientific conception.

What Happens When Visible Beams of Light Travel to An Object?

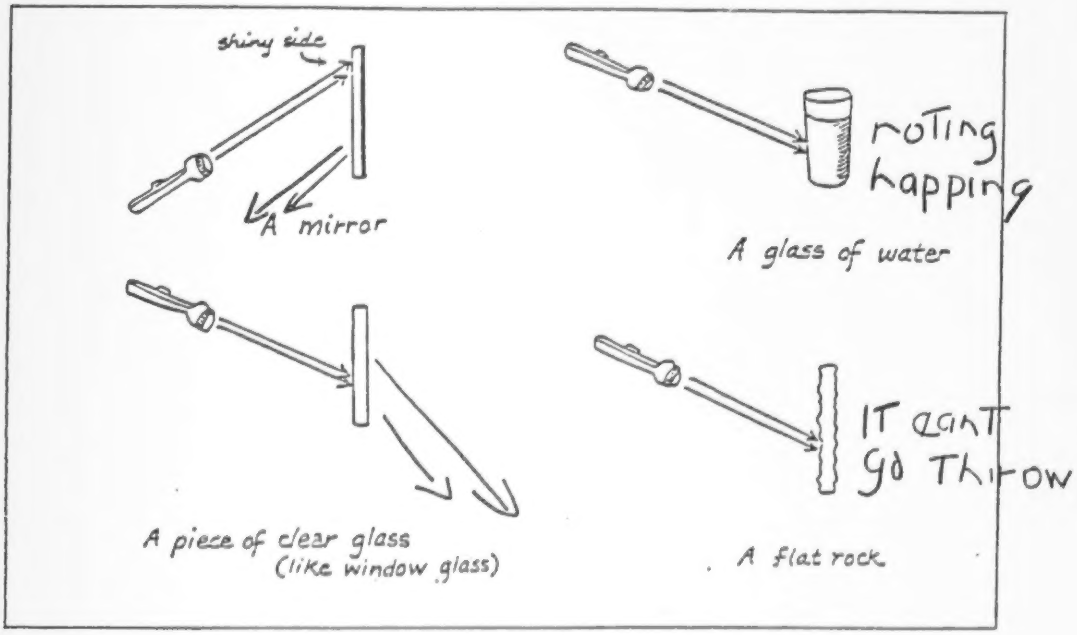

shiny side
A mirror
roting happing
A glass of water
A piece of clear glass (like window glass)
IT cant go Throw
A flat rock

Figure 6-10. What Happens When Visible Beams of Light Travel to An Object? Martin's Response

Comment: Martin notes that light passes through the translucent piece of window glass, but appears to not believe that this occurs with the glass of water. He notes that the light does not pass through the rock, but does not comment on what happens to the light rays after they strike the rock.

Why Do We See Color?

> Well, if something's got like a red dye in it or some other sort of dye in it, that's what we see. And if there's not enough, it could look like a different shade. Or if it's a little dark, say, then it would be a little different shade.

Comment: Martin believes that color vision is a function of the color being in the object observed.

Feelings Associated With Light and the Study of the Topic, Light

> Oh, man, wow, like um, I got zapped by a light when, um I exploded a light bulb with my dad's car battery and another time, well, um I sure did feel it (laughs) because I got this really strong, you know charge? Like when I put two um, wires like you know, um the red and the black one, right, are the one way, I well, like I put em the other way around and got this jolt and there were sparkles all around and in my eyes, boy!
>
> I really like to study science. It's my best subject. So whenever we can, like, when we did some stuff with light in grade two I think, I showed the teacher some ways to work with electricity. I had this book and I showed her what to do and all. I'd like to know more about light, sure. Who wouldn't?

Comment: Martin has had quite a bit of experience tinkering with electricity and lightbulbs. He seems very eager to explore the topic light, or any topic in science.

6.8.4 PART III: Personal Orientation to Science Learning: Revisiting the Study With Personal Constructs and Emerging Themes - Paradigmatic Instances of Thought and Action

Martin's Personal Constructs

Martin's personal constructs and ratings of science experiences while learning about the topic, light, are presented in the Repertory Grid Chart, Table 6-9. His comments on the factor groupings of the constructs are shown in Table 6-10.

Table 6-9.

MARTIN'S PERSONAL CONSTRUCTS

1. Working with other kids to find out.	5145133435141214511215532322212125133	1. Mr. Don is just telling you.
2. Getting or giving help.	1211323222312231242231211545414555342	2. Just doing your work yourself.
3. Thinking up what to do on your own.	4245123414242445411112442111141335244	3. Being told what to do.
4. Working.	1414311112411251222334211534414554121	4. Goofing around.
5. Showing what you think and feel.	4233142331341424321152451322111535142	5. Just correcting the worksheet.
6. Creating new ways to do things.	5445433435243345251344212543313535143	6. Just writing down the answer.
7. Going ahead and trying.	1112112124232425312141211414231544141	7. Stuck. Having trouble understanding.
8. You know what you're doing and can do it.	5254313434322545242344421542122554142	8. You don't know what you're doing.
9. Playing around, experimenting around with the equipment.	4212312223243352222223323223222534143	9. Working on your worksheet.
10. Easy work.	3544423543443514442221254542144525343	10. Hard work.
11. Having a good time in my work.	2213133225232454322153221553111444142	11. I'm bored and I don't want to do it.
12. Really interesting new ideas.	4333434544352414342322412442143555153	12. Boring, repetitious stuff.
13. Confronting new ideas.	2111112244413121432144431344221445151	13. Just sitting there doing nothing.
14. You get if figured out.	4354344534243244351331234444135425444	14. You're trying to find a way to figure it out. You're working on it.
15. Talking to find out what to do to figure things out.	5315214545342444452254212244225553122	15. Just listening to the teacher.

Table 6-10.

MARTIN'S STATEMENT GROUPS

Group 1

Showing what *you* think and feel.
Creating new ways to do things.
Having a good time in my work.
Confronting new ideas.

Martin's Statement: This is all about enjoying myself and expressing my own ideas.

Group 2

Creating new ways to do things.
You know what you're doing and you can do it.
Having a good time in my work.
Talking to find out what to do to figure things out.

Martin's Statement: Creating new approaches is intersting. I like to be creative whenever I can. Sometimes the teachers let you be creative.

Group 3

Working with other kids to find out.
Just doing your work yourself.
Thinking up what to do on your own.
Goofing around.

Martin's Statement: This is about working with other kids and on my own. I guess the work is sometimes, well, it *can* be sometimes like playing.

Group 4

Easy work.
Really interesting new ideas.
You get it all figured out.

Martin's Statement: When it all fits together, all the pieces, then, it makes it more interesting. Like, when I'm understanding, man it's smoooooooth sailing.

Emerging Themes In Martin's Personal Orientation to Science Learning

Theme I. *Self Characterization*: I like expressing my own ideas and creating new ways to do things.

Researcher Image/Impression: Science as a vehicle for personal expression, creativity.

This theme reflects Martin's intense interest in the science learning experience as a form of *personal* expression. Throughout the term, he actually shows very little tolerance for considering ideas which he has not discovered himself, or which he does not believe are true. In the following example, for instance, he speaks of his strategy of "just forgetting" an idea which does not make sense immediately. He speaks of "throwing away" an entire lesson sequence if he does not instantly understand what he is to do.

In the first lesson, Martin and I discussed his reaction to Mr. Ryan's unusual statement to the class, "The reason that I see Martin is because light is coming from him into my eyes."

Martin: Well I really didn't get that. So I just forgot about it.
Ms. Shapiro: Do you think that he was right?
Martin: Probably he was. What the teacher says, *goes*, right? But *I* don't think so. It doesn't make sense to me. Not to me. So...if it doesn't make sense, I just don't worry about it, I go on, just go on. If I can't see it, how can I think that? Sooo...just have to go on.
Ms. Shapiro: Oh, I'd be bothered by that I think.
Martin: Nope. Not me. I just forget it and do something else.

In fact, during the review of the videotape of Lesson 6, "Bend That Beam," Martin watched himself struggle with reading the instructions on the worksheet, and with the idea of light bending as it passed through a beaker of water. He turned to me as we reviewed the tape, "I threw this whole lesson away. I didn't even want to be there."

Ms. Shapiro: You aren't enjoying the light unit?

Martin: I *was*. I was. You know, like *before*. But not now. Cause, Mr. Ryan, like he's showed us all of this stuff already! I want something different. It's getting boring, just the same stuff as before. So, I wasn't even there. I threw the whole lesson away in my head. The light goes through the beaker and crosses. So? We saw that before. So I want something new. New, new, new. More technical.

Ms. Shapiro: What do you mean by more technical?

Martin: Well, like something else happening, man. Some new ideas to think about. You know? Um, different. More about light. Not review stuff, man.

In fact, the lesson was not a review, but introduced a new idea which Martin was not grasping. Though he had described what he observed, the crossing of the light beams, he was not grasping the main idea of the lesson, that the light rays were in fact *bending* as they passed through the water. The fact that they eventually crossed was because *the water bent them*. This idea was the key to the development of the concepts to be introduced in the lesson on refraction.

Martin's description of this activity using his construct, personal construct, "Boring, repetitious stuff" portrayed his willingness to carry on with an activity only if it is of immediate interest to him and represents the promise of some new visual experience or manipulation. This requirement appears to determine whether or not he is willing to continue on with an activity or even to be involved with the lesson at all. By contrast, he is using description from the opposite pole of his construct "Really interesting new ideas," when his involvement is intense and expressing his new ideas with others. It can be seen repeatedly in reviewing Martin's videotapes that the struggle which Martin has reading the directions on the worksheets obviously frustrates him and keeps him from the sense of full involvement and expression in the experience which he values so highly in Science.

As Martin had described his desire for "really interesting new ideas" and his very great impatience with "boring repetitious stuff." I asked him to describe the new ideas which he believed were presented in the lesson to better understand just what he found boring about them. Martin told me that he believed that the main idea presented in the lesson was that the beams of light passing through the beaker bend or refract. When they do this, the beams converge at a point beyond the beaker.

I asked Martin to explain what it was about the lesson that he felt that he had been through before.

> Well, the beams bend down at this point. That's refraction. The bending, when they bend down. Right

> there, and then see, this is where they bend up. So? We did that already.

Martin had not understood the reason behind the bending. He focussed on the result only, the fact that the beams crossed. He therefore equated the crossing with the bending of beams. Although he had seen light rays crossing before, it was due in previous examples to the reflection of light rays, not the bending of light rays. Martin had made a similar error to Donnie's in seeing refraction or bending as that which happens at the convergence point. I asked him to show me where the convergence point was.

> Oh, that's where the beams go on and on forever, here. (points to the beams). If you could see that far, they'd go on forever.

Of course, the convergence point is just the opposite. It is the point where the beams come together. What Martin considered was his "boredom" with the lesson was not so rooted in the fact that he had "done everything before," but Martin was clearly not understanding the main ideas. Yet his boredom does originate in the actuality that he is not interested in the development of ideas in the lesson. He is interested in his own involvement with the materials, with expressing his thoughts about this involvement and in "coming up with new ideas." And so, Martin is focussed upon his own interest and agenda. He had seen this effect before. He's not interested in seeing it again. The agenda of the curriculum maker, however, is to provide examples to the students which illustrate two different concepts. In this particular curriculum package, the distinction between reflection and refraction is not clearly made for the student, and it does not take into account the orientation of a student such as Martin, whose greater interest in the materials is in personal expression through the doing of the activity. By the same token, Martin would benefit from attempting to look at the materials from the point of view of the intents of its authors, to ask, for example, what is the main idea of this lesson? The curriculum makers could more effectively communicate ideas with students by attempting to understand how the materials are actually experienced by the variety of students who 'consume' them. This communication is not only just two-way. The teacher-as-mediator of student experience must have an awareness of the need for students to be helped to take responsibility for their own learning.

Martin often makes a point of appearing unconcerned with any sense of responsibility, yet this may be because of the intense frustration which he has experienced in his attempts to understand. We talked about Mr. Ryan's discussion of refraction:

Martin: Oh. I don't remember refraction. I don't remember what it means. I really don't care.
Ms. Shapiro: You aren't interested in knowing about it, I take it.

Martin: No. Cause what good is it? The words are all hard and they don't help you, like you can't do anything with them?

Ms. Shapiro: I wonder, did you notice the comments that Mr. Ryan made here on your sheet about your answer?

Martin: No. (laughs) I never read them. I figure, you get it wrong, you tried, right? But you got it wrong. You get it wrong, so you get it wrong. With this stuff, sometimes I just want to do it, get it done, finished, goodbye, go on. I want some new stuff now.

Martin's Interest In "Doing"

As these examples show, for Martin, what is of continuing interest and vital interest in the science lessons is the actual first-hand experience of manipulating the equipment and materials. Martin appears to be telling himself and me that these experiences must be new if he is going to be interested in paying attention. And these must not be just new ideas, but these must be new experiences -- adventures which are new and action-packed!

Martin shows good ability to deal with new ideas, but his expression of ideas is spontaneous, exuberant and "in sudden excited "flashes." On one occasion Martin and I were reviewing a videotape together in an interview room in the school. The room was glassed in on the side facing the hallway allowing us to see the comings and goings of persons in the office area. As we watched the videotape, Mr. Ryan pointed out how light can be both reflected and bent at the same time. Martin watched, then very suddenly commented, "Hey, look at the light reflecting off of this side of the window!" He then looked up at the glassed side of the room and exclaimed,

> Look! Hey lookit! The light! The light! You can see it, like bouncing off the window this way *and* you can see it going right through the glass! Wow! That's cool, man! I never saw that before!

Martin had noticed the reflection of light from the glass while at the same time he observed beams of sunlight passing through the glass to the hallway. He was thrilled with this discovery. About one week later, Martin attempted to share this insight during a class discussion of prisms. Mr. Ryan was explaining that the rainbow colors were produced by *both* the reflection and the bending of light.

> Mr. Ryan: Yes, Martin?
> Martin: That's just like, um when I was talking with Ms. Shapiro the other day, that's, um we saw that the light in the room was bouncing off the glass window *and* it was passing through the window. Is that like a prism?
> Mr. Ryan: Not quite, Martin, there has to be an angle that the light bends at for us to see color. It must have been sort of shiny so you saw that, you noticed that.
> Martin: Well, the light was sort of bright. Hey, is a prism then, sort of like a *diamond*? Is that the same thing as a diamond? The way it makes the light go?
> Mr. Ryan: Well it does work the same way, Martin, but this is just glass, a diamond is a special piece of um, a mineral. But yeah, and that's why girls like diamonds so much, Martin, because they're sparkly and pretty.

Although Martin's spontaneous insight provided an opportunity to re-emphasize the main point of the discussion, it was unfortunately diverted by Mr. Ryan's remark. Martin did continue to pursue the connection between his experience and the lesson, but this example demonstrates his interest in making connections between his own first hand experience and the concepts being presented.

In another example, Mr. Ryan had been speaking to the class about the density of liquids and how light beams were bent differently through liquids of different density. The students had not performed any activities to demonstrate this phenomenon due to lack of time in the unit. Mr. Ryan had discussed it with the class only because he felt that the actual experience was not crucial to the development of ideas in the lessons which followed. Several days later, Mr. Ryan reminded the students of his verbal explanation of light passing through various liquids in preparation of the next lesson. Martin waved his hand wildly.

> Martin: I, um you know what you were saying about different liquids and stuff? Well, at breakfast I tried all kind of stuff. I shined two flashlights through water and then through orange juice.
> Mr. Ryan: Orange juice?
> Martin: Yeah (excited) Yeah, and then um I put milk? Like a few drops of milk in the water, in a glass of water. And they were different. And then, cause, um my mom had gone to work? I got out some cooking oil and shined it through that too, and it was about the same as the orange juice.
> Mr. Ryan: Well, good, Martin, good. I'm glad that you tried that and told us about that. Orange juice surprises me. I've never tried that. Good, good.

Martin appeared very pleased to share with Mr. Ryan and the class the activities which he had tried at home. He had the complete attention of the class, and was able to share something creative and different which he had discovered on his own about the light beams.

Martin reiterated his interest in working things out, figuring things out for himself during Lesson 9, "Believe It Or Not." The students looked through a beaker of water at the word "LIGHT" they had written on a piece of paper. The paper was to be first held up against a beaker, then was gradually moved 10 cm at at time, away from the beaker. As the paper was moved away from the beaker in this manner, the word was to have appeared reversed when viewed through the beaker of water, but to most of the children it appeared only as a blur. The children were to move the paper away along a meter stick, then watch to see at which point the change in the word actually occurred.

Martin was one of a very few students who actually saw the word and its reversed image clearly through the beaker. Mr. Ryan had visited Martin's group early in the session and had shown the students how to hold the paper and at what angle to look through the beaker. Though Martin did not understand the reason for the reversal of the image in terms of the explanation which Mr. Ryan had given, he was very successful in the actual manipulation of the equipment.

Martin therefore achieved the correct response on his worksheet, but did not possess the understanding which should have accompanied it.

As we watched the videotape, Martin remarked on his appreciation of the teacher's guidance in helping him to achieve success in this activity:

Martin: You don't learn anything by just putting up your hand and giving the answer to the questions. Like Mr. Ryan usually gives a clue or um, usually not the answer. Because if the teachers don't make you challenge to do something, you're going to get lazy and you want always to um, want help and all that. That's what the teachers are trying to get away from. My dad is um, used to be a teacher. So that you'll on your own will, you'll try to work out the problem out by yourself without much help. If you always ask the teacher, the teacher always comes and gives you a better clue than actually giving you the answer. I don't think that is what a teacher should do.

Ms. Shapiro: Mmhm. I've been trying to find out more about how students are thinking about this. So you believe that the teacher should not give the answer directly to the student?

Martin: I think if you want to give your students to be one of the best students, to keep them interested in the thing and you don't just tell them the answers you give them clues to build on. And when he builds on that, when it came up, you'll go, yeah, I remember this, and you can just write it down.

Though Martin might be considered one of the lowest academic achievers in the classroom, one of the most impulsive and difficult students, in the classroom he was also one of the most expressive and verbal individuals--a very frequent contributor to classroom discussion. The first and second themes of Martin's personal orientation interweave as Martin's personal, expressive need in Science class is also dominantly physical. Martin values highly activities in which he can become physically involved, which have a coherence in which he can, guided by the teacher, experience a type of closure and a sense that he has done it, that he has discovered the answer, as he has said, "by his own will." Though the other children do value the opportunity for physical involvement in science, it has a particularly important meaning for Martin. It appears to constitute a dominant interest and orientation in science learning for him. Donnie's orientation is similar to Martin's, in that she seeks to figure out the solution to problems by her own efforts, but Donnie is more concerned that she actually understand the ideas that the lesson materials and Mr. Ryan are presenting. She becomes entangled in the processes of reasoning and thinking which allow her to come to understand the phenomena being discussed. Martin on the other hand, seeks solutions in working with the materials. Donnie feels that she somehow should be able to understand the phenomena through her own thinking efforts, that is, her conversation with me reveals that she believes that if she only concentrates hard enough and puts forth sufficient effort, she should be able to figure things out. Martin believes that with the teacher's guidance, or clues that he will figure things out as he manipulates the materils. But if not, Martin says, "well, then I just forget it." Donnie's mission is to understand in a deep and personal way. If she does not, she is disturbed.

As I reviewed and contrasted these two personal orientations to science learning, I began to wonder if, in fact, in contrast Donnie may have been too worried about deeply understanding the material and feeling that she should be able to come up with the same ideas as the physicist who had created the explanation. Martin was very interested in these questions, but it did not seem to disturb nor affect his view of himself as a success in science when he could not answer all of the questions.

The second intertwining theme of Martin's personal orientation to science study refers to enormous value which he places on the physical involvement in the activity.

Theme II. Self Characterization: I usually think up all the things to do in the group. I do them and the other kids just write it all down, all my answers.

Researcher Image/Impression: Enjoyment of physical involvement with the materials, the doing of activities. In his joy in manipulating materials, taking things apart and putting them back together, Martin is the consummate tinkerer.

In contrast to the difficulty which Martin experiences in reading and mathematics, his overall emerging pattern of personal orientation to science learning is revealed as an intense interest in science as a form of active, concrete experience. He sees Science class as an opportunity to express himself creatively, and continually informs me of the joy which the experience of active involvement with the activities and materials which science learning provides.

Conversation with Martin, a review of his personal constructs and his comments on his clusters, shows him particularly valuing the chance to "express my own ideas" which he associates with "having a good time in my work."

Martin had difficulty with all of the written aspects of my initial surveys, which made our conversation time all the more valuable. My usual practice of jotting down a note or comment during conversations with the children in the study group was completely dropped after one session with Martin. Martin was remarkably verbal. He spoke quickly, but did not seem to be able to tolerate pauses or lapses in our converstations. My solution was to tape record every session with him, and to make very few notes.

Martin was very interested in my research involvement with the class and had many questions about the purposes of my project. He often offered his opinions spontaneously and what he believed were the opinions of family members on the quality of current educational practices. In all conversation with Martin, I found him working hard to take the directing role in the conversation. Martin also appears aware of his own need to find his own way in learning:

> You know, sometimes the teachers let you be creative. Do you know what I mean? I like to try creating new ways to do things when we do the activities."

Martin contrasts his personal construct, "Thinking up what to do on your own," with "Being told what to do." He contrasts his construct, "Showing what you think and feel" with "Just correcting the worksheet." These constructs demonstrate the interest in the personally expressive nature of the experiences and the boredom of being asked to do as you are told. This distinction intertwines with the physical involvement with the activity which appears to be so important as I observe him working, the focus of Theme II. Martin values "working with the other kids to find things out" and frequently comments on the challenge of "getting it figured out, like how it all works." Martin speaks metaphorically of science learning. "It's sort of fitting the pieces all together with clues and questions from the teacher." Throughout our conversations, Martin makes reference to science activities themselves and to the doing of them as being, for him, the most meaningful and important aspect of his experience of science learning. His consistent reference point is the activities themselves, the active performance of tasks.

Throughout my conversations with Martin, as we reviewed the videotapes of lessons, a pattern of tension emerges which underscored the gap which exists for him between the meaningfulness of active, physical involvement and his difficulty in academic achievement in school Science and in other subject areas.

The pattern which emerges shows Martin to be quickly dismissing and rejecting ideas and experiences which he cannot quickly respond to or grasp. The special meaning of learning science for Martin is embodied in the pleasure of the experience of concrete activity, but when he is not able to immediately grasp the main concept of a lesson or when he is not able to read the instruction sheet to find out how to carry on in the activity, he is often extremely impatient with the activity. When he does not understand what he is supposed to do, Martin very quickly becomes bored. Mr. Ryan remarked, after one incident in which Martin appeared frustrated and was complaining about not understanding what to do quite loudly:

> I don't know exactly what the problem is with Martin. He seems to like Science and he does well when he's interested. But sometimes he just can't seem to control himself. I wonder sometimes if he may be a bit hyperactive."

Martin has shared some of his own thoughts about his working habits and approaches to science learning. For example, he realizes his preference for moving quickly from one task to another. The following conversation, a prelude to a videotape recall session, began with Martin telling me about one of his most recent projects at home:

Martin: You know, I'm making a bird cage out of a little piece of wood. For a little bird nest? And I thought maybe for a science project. I'm doing it at home in the garage. I'm having my neighbor help 'cause he knows what kind of drill to use.

Ms. Shapiro: Oh, this is a project for school.

Martin: Well, not really, just on my own. I like to do a lot of science stuff at home on my own, because I don't like to get stuck on one thing for a very long time. Like I'm doing something? I'd like to do something else, right away. Like, if I'm working on a like, if I finish a project, right? Then sometimes I might start screwing around with something else even while I'm still working on the other thing, or something, and I like, I don't like to stay at one thing too long.

Ms. Shapiro: A lot of people are like that. They like to keep several projects going at once. Is that true in school too?

Martin: Well, I don't like to stay on one thing too long. But in school, not really. Cause as long as it isn't too hard. Cause, like if I know what's going on and stuff, then I just am right there with it, I don't move from it, you know? I'm just right there. But if I don't get it or say, like if we've done that before, man, let's get outa here! (laughs)

It is worthwhile mentioning at this point, that the children with whom I have spoken have shared far more with me about their own learning than I would ever be able to adequately portray. The presentation of examples for theme development must, through the constraints of space be selected from only a few instances. There were so many to choose from for Martin, this was particularly difficult. Through talking with Martin, I was continually amazed by the extent of his awareness of his own approach and style of working. He possessed an unusual facility in conveying this awareness to me. Melody (Case Report IV) possessed the same ability to reflect on her own learning, an attribute usually thought to be found only among more academically successful students. During the ongoing conversations with the children I have found continually that the children have a remarkable ability to reflect on their own learning experiences and their own styles of involvement in Science. Clearly Martin, has shown tremendous ability to consider, to reflect on, and to share with me what he believes to be his particular approach to learning science, and in this respect he is not different from those children in the study who are regarded as the more "able" students.

Again and again, I found Martin and the other children to show great insight into their own approaches often expressed in highly philosophical ways concerning how they create their own meaning and what it means to them. Yet this flies in the face of an attitude on the part of many theorists who suggest that children are not capable of such reflection, and that their comments cannot be taken seriously. Robert Coles (1984) refers to

> ...this skepticism, this outright refusal (by some rather authoritative figures in our intellectual tradition, and, of course, by those of us who heed them) to acknowledge capabilities demonstrated time and again.

He argues that a denial of students' capabilities results from the research practices which build upon and perpetuate their own limited views of childrens' abilities: Coles points out that:

> Such theorists do not really relax and talk with children day after day; rather, they ask them pointed questions, get them to perform tasks, then grade them.

Matthews' (1980, 1984) insightful conversations with children allows us to consider children's questions and contributions to conversation as serious and important additions to the ways that we think about child thought. This was particularly evident in Martin's situation and was even more important for him as he was considered to be a slow learner having many academic and social difficulties.

Martin was able to reflect on his approach and interest in science learning:

> Science is one of my best subjects. I like it as much as gym. Science is a chance for you to really get a challenge and it's one of the only times you get to use your brain to figure things out. I do things, sort of science-type things at home a lot. In my spare time I'm always taking things apart, like ever since I was really little. Like and my mom always brings home the broken toys from the place where she works like and she tells them 'my kid like, likes to take things apart,' and I, then I like to fix it and figure out how it goes.

It appears that Martin is the consummate tinkerer and that he is encouraged to pursue this interest by his family. An important aspect of the special meaning of science learning for Martin resides in the enormous pleasure which he speaks of deriving from the physical manipulation of objects and the discovery of how things work.

Each encounter with Martin is an exuberant re-enactment of his most recent adventure in taking apart the family blender or vacuum cleaner, of fixing a radio or toy, he gleefully details the recent blowing up of light bulbs using the family car battery. After the description of a disastrous experiment with the kitchen blender, Martin asked me not to convey his escapade to his family should I happen to see them. Although they appear to encourage his tinkering interest, Martin is aware that he takes apart beyond his ability to put back together. In these adventures and throughout the discussion of the class activities which we observe on videotape, Martin spontaneously describes in detail the procedures which he has employed, the various tests which he uses to find the answer to a question, which procedures have worked and which have failed. This continuing effort and the excitement of being involved in the doing aspect of the experience of science, the clarification of what "works" and what "doesn't work," are dominant and pervasive themes but in the ways that he lives out the experience of learning science in the classroom.

A third theme of Martin's personal orientation to science learning surrounds the importance of social interaction. This theme illuminates Martin's need for the help of others and also shows his interest in proving to others the abilities which he possesses.

Theme III. Self Characterization I like expressing my own ideas with other kids, not keeping it to myself inside and all. I like trying out my own ideas and going ahead.

Researcher Image/Impression: Value of the social interaction with others who help him in important ways to pursue his own aspirations and interests, and to gain self esteem through the interaction.

Again, an interweaving of themes is evident in Martin's conversation concerning the value of working with others. In particular, Martin needs help in reading the worksheet to understand what to do.

In George Kelly's view, individuals behave in the manner in which they do because it is from this stance that their world has the greatest meaning. To understand the meaning which the person ascribes to science learning allows us to understand the behavior in the classroom when the individual is confronted with new, unfamiliar science content. As can be seen repeatedly Martin has developed the social skills which allow him to secure the help which he needs to read the science worksheet instructions. This allows him to secure the help which he needs to read the science worksheet instructions which gives the science lesson such great meaning for him.

During the lesson "Bounce Those Beams," for example,

Martin explained:

> In this lesson, like, I was trying lots of ways and um, the other kids were writing things down. That was great because I had um, some trouble figuring out what to do like, um. Right there I was, Steven, there, in a second he is going to ask me what I'm doing and um, um, what I'm doing in a second, see there he is asking me and I showed him what I was doing. See, I'm saying, 'What does that mean there on the worksheet, I was starting to write.' On the other page there, I made Steve read the whole thing and I wasn't even listening (laughs). I was busy trying out some ways of bouncing the beams. Like, I was trying to figure out how to do it as I went along.

Ms. Shapiro: You were working along there and didn't understand the question?

Martin: Yeah, I was working on it. I had, um, I just asked Amy. She's telling me what to do and once I got it straight I just went right on and tried all the different ways that I could think of . I had, well, I could understand it and I just had trouble, but, um, reading it, though, once Amy gave me those two words, I couldn't get, I just said, 'Here I go how about this way -- try this. And this way I was the one that figured this out, um how to get the beam reflected around the book. Um, Mr. Ryan he said that nobody had figured out by my way, and so um the other kids, um the people in my group, they put my ways down a lot because I always get things figured out.

This conversation shows how aware Martin is of his own ability to "figure things out" and how important is the esteem of his classmates and teacher who show admiration for his ability to solve difficult problems. Martin values this talent. He also values persons with whom he has a working rapport, persons who enhance his own orientation. Of the three students in Martin's activity group, two, Amy and Melody, are also working closely with me in the study group. Amy, whose story is described in case report V, has a strong task orientation to science learning. In her constructs and conversation, one of her primary missions is to work to understand what to do in the lesson. Then all of her energy and resources are devoted to the accomplishment of tasks. Because of Amy's very strong reading ability and her task orientation, Martin often secures Amy's help to understand what is to be done in the lesson, then he and Amy often compare thoughts and ideas as they simultaneously work to figure out a solution to a problem. He often aligns himself with Amy in his effort to carry out his own mission of involvement in science learning, in doing and of being involved in the experience to the fullest extent possible.

As strongly as Martin aligns his efforts with those of Amy, he is seen to misalign with Melody, also a participant in the research study. Melody shows a strong interest in the aesthetic aspects and features of the activities, an aspect which is also shared, though less often, by Amy, Donnie, Mark and Peter. But Melody has an overriding interest in the social interaction within the group, and among members of the classroom. These are the aspects of learning about science which are of greatest value and interest to Melody. Because Melody's particular orientation to learning often runs counter to Martin's, the resulting consequence is that she often actually thwarts the orientation which Martin has demonstrated. Martin's interaction with Melody punctuates the differences in their orientations. Martin is, at times, hostile towards Melody when the group is engaged in an activity, as both students attempt to live out their anticipations and expectations for science learning. Martin's orientation to science learning sees him aligning with some members of his group in what is for him a productive association. But Martin also comes into conflict with persons who thwart his learning mission, a particularly intense clash in his interaction with Melody.

Martin's Personal Orientation and Small Group Interaction

During the lesson, "Lenses and Light Beams," the children are to set up an arrangement of materials so that two beams from the light source pass, this time, through a magnifying glass instead of a beaker of water. In the second portion of the activity, the children describe the beams and compare the behaviour of the light through the lens to the light through the beaker of water. Finally, they look at a card with the word, "Light," printed on it, through the magnifying lens held at various distances from the card.

> Karen: Oh, hey! Look at this! Look at the numbers!
> Martin: Oh, did you see that! The light!

Look at this! Wow! Neat! Look at this Steven. Look, look, look at this Steven. Move it. Look what happens when I move the light.

Steven: Neat. So, what do we do?

Martin is experimenting with the visible beams from the light source and magnifying lens. He is very excited about the results and wants to share the experience with Steven. The joy of his discovery of the unusual behavior of the light beams through the magnifier appears to give him a great incentive to try to read the directions to find out what to do next.

Martin: Ok. (Reads) Um, set up an ar--ar--ange

Steven: Arrangement

Martin: Ok, set up an arrangement so that two beams from the light source pass through the magnifying glass. Place a sheet of paper on, er, um, under the ararange-ment.

Steven: Yeah. We did that.

Melody: Martin, Martin...let's double it. Look. Oh, pretty. Martin, Martin.

Again, Melody is trying to distract Martin and is about to ask to use his magnifier. She wants to place it on top of her own to see what the doubling effect will be. However, this is not one of the tasks the students were being asked to accomplish, and Martin ignores her.

Martin: (to Steven) I don't get that. What are you supposed to do?

Melody: Martin, Martin. Could I see your magnifying glass?

Steven: Look at the worsheet again.

Martin: Okay. Set to up the arrangement without the water, right?

Steven: Okay, here I'm putting it-

Martin: It goes straighter! It goes straighter!

Steven: Okay, you've got to have the two beams pass through the water-

Martin: Hey look it crosses! Oh, um. (Denny has come over from his group to watch, and bends down to see) Hey, Denny, get out of here! Hey! Hey! I know! I know! Maybe it gets brighter! Maybe that's what it does!

Martin is so excited by what he is

seeing that he continually interrupts Steven and grabs the materials away from him. Denny has wandered over to Martin's group. He is also trying to find out what to do. Martin sees his approach as an interference and makes Denny go away.

Steven: (to Melody) Look. Gimme my magnifier.
I want to do this.
Martin: Hey! Look! Here is where it crosses!
Denny: No. You have to look way up here.
Martin: No you don't.
Amy: Two light beams. Look, it crosses.
Martin: (Disgusted) No, it doesn't! (Looks again)
Hey! Oh, yeah, it does! Get outa here
Melody! (Melody has reached over to move
the light source around.)
Melody: I was trying to fix it. Martin, let
me use your magnifier.
Martin: No. Get outa here. We're trying to
do the activity.
Melody: I just want to use it for a minute. You're
supposed to share. (Melody moves the
beaker around to create a new effect with the
light rays.

Martin: (to Melody) Hey, don't! Hey, that's
not what we're supposed to do, Melody.
Get out here. Do what you're supposed to
do.
Martin: (Returns in disgust to his activity)
Okay. Steven, what do we do, man? We draw
it and write it? Read this, man.
Steven: (Reads the directions again out loud)
Oh, I get it now.
Martin: (Is working with the light source)
Look, it gets closer and closer. Look! Look!
(Martin is manipulating the materials.)
Steven: Look what it does. It crosses and it gets
brighter too!
Melody: OOOooh! Neat! Wow, look!
Amy: Neat, eh?
Melody: Yeah. Hey, look you guys. Look
through the top of the light! (Looks down into
the light source box) Hey, it seems like, um it
looks like it's just grass down there.

Melody has now succeeded in pulling the others away from the task to follow a lines of inquiry which she has spontaneously chosen. Although she takes them off the track, each person makes his or her observations about the light which all of the children are sharing. The group then has a discussion about the heat which they feel from the shining light source. This important basic property of light, is actually not mentioned at any point in the light unit.

Amy: (Still looking into the light source.) Hey. Look. It looks like you can see a little school in there.
Steven: It looks like peat moss. All kinds of little things around.
Martin: Oh, weird. It's all sorts of little silver things. (Reaches down) Oh, ouch! Hey! There, boy is that hot! That's really hot! Man, I burned my finger.
Amy: Yeah. My hand is way out here and it's it's hot.
Martin: (Going back to the activity) Okay, Steven. Let's draw this. There. I drew mine. Hey. Look what it does when you move the beams.

The students have made a spontaneous discovery concerning the association of heat with light. Though one of the fundamental properties of light, it is interesting that this physical aspect of light is not mentioned in the curriculum materials. The unit actually emphasizes the interaction of light with objects in the environment only and does not stress more fundamental ideas.

At this point in the activity, Martin has quickly gone back to doing the task. He works with the light source, trying to read the worksheet once more to find out what to do. His difficulty with the reading is once again too great, and he enlists the aid of his friend Steven. This enables him to continue.

Melody continues once again to suggest that the group work, not from the worksheet, but from her more spontaneous interest in the phenomena. Martin reacts strongly to this distraction, and intrusion on his own interest in doing the activity as outlined on the worksheet.

Melody: Hey, neat! Lookit! It looks like a bug! Lookit, go like this. (She tries to manipulate the light source)
Martin: Whaaaat? Who cares! Get out of here Melody! (He pushes her aside). What's this word, Steve? Steve, hey. What do we do, man?

Martin appears to be very frustrated with Melody at this point. He commented during the replay of the lesson that "All she ever wants to do is fool around. She never tries to figure things out. Just do what she wants to do. She's all over the classroom." Mr. Ryan comes over to the group and Melody asks him:

Melody: Oh, Mr. Ryan, you know what we discovered? Lookit what we discovered!
Mr. Ryan: Ok. What did you discover about question one?

Melody begins to talk about the shapes inside the light source and Mr. Ryan repeats his question sternly. Martin is listening to their conversation and responds:

Martin: Well, like the light source right, the light coming from it is really wide now, right? And it's not as bright. But when you do put the light here it gets closer, too.
Amy: And it gets bigger.
Mr. Ryan: Let's have a look. Let's see what happens.
Martin: (Martin is holding the worksheet and appears anxious to continue) See, it gets bigger and then...
Mr. Ryan: What does it do?
Martin: (Excited) It goes across. It crosses.
Mr. Ryan: Oh, that's right. So the two narrow light beams go through the magnifier and

> they-
> Amy: Cross. Neat.
> Mr. Ryan: Do you see them crossing way back over there?
> Martin: No. (Martin works with the magnifier and the light source.) Oh, yeah, it does, yeah.
> Mr. Ryan: (Stands up and addresses the class) Okay. We've only got ten minutes to carry this through.
> Martin: Okay, um Mr. Ryan. Mr. Ryan, what's this word?
> Mr. Ryan: Evidence.

Martin continues to ask the students around him for help reading the worksheet even as they are all preparing to leave. I watch as he intently continues to work by himself to work on the activity throughout the clean-up period and into recess, one of his "ace-favorite times." This persistence in light of the great difficulties which Martin has in reading and writing and the fact that it is recess are further evidence of the great joy which he takes in science learning. We have seen that he finds some of the abstract concepts in science difficult and even annoying, but his enthusiasm for participation in the activities and in physical involvement with the materials overrides these problems. Science is one the very few classes in which Martin finds a sense of achievement and success.

6.9 CASE REPORT IV: MELODY

6.9.1 Some Initial Observations and Impressions

Along with Martin, Melody is a member of a group of six children in the class who receive remedial instruction in reading and mathematics. Their teacher, Mrs. Kay, comes into the classroom two mornings and three afternoons a week to work with the children in these special areas. Melody was immediately friendly towards me and spoke with me often in the classroom. Often on the playground she would accompany and talk with me as I walked around. Often she would hold my arm as we walked. Early in my stay in the classroom, Melody made a special point to explain to me why she met with the Mrs. Kay's group. I'm in this group because I don't have the higher scores in math and reading that some of the other kids have. I need help in these subjects because sometimes I don't understand the math sometimes, I don't get it.

6.9.2 Thoughts and Feelings About Learning School Science

Initial Conversations

When asked, "How do you feel about learning science?" Melody checked the highest possible positive statement on the survey sheet, "I really like it!" On several occasions thoughout our discussions, Melody spontaneously commented to me, "OOOoooh, I like coming here and doing this [discussing the videotapes with me] I just love Science. It's so much fun. You get to do so many neat things."

Melody contends that Science is very similar to some of her other subjects, but that there are some differences.

> Science is not so different from language and it's sort of like health. In science and health, like, the kind of health we're doing now, um you're learning about how to do different stuff like we're studying on teeth with Mrs. Andrews and like you get to learn what teeth can do to you, how they can help you. And we learn in science what light can do to you and how light can help you.

She sees a difference between learning about science at school as contrasted with "the kind of science that I teach myself at home."

> After school I see lots of interesting stuff and I see a lot of stuff and well, sometimes I don't pick it up because it could make me sick. Last year, I used to live in the country and there's a pond near our house and it was sort of a forest all around it. And there were strawberries, not strawberries, um, raspberries? A big patch of raspberries and I seen a whole bunch of interesting bugs and flowers and we seen a lot of strange types of moss and that. Well, that kind of science doesn't help me in my life, but the kind of learning I do in school does. Like the science that I teach myself at home sort of just gets me interested and I've started liking certain things, like I used to collect rocks and that and that was interesting to me, but I don't collect them any more because we used to have this long road in the country and there used to be a lot of pretty rocks.

Ms. Shapiro: So you feel that seeing these rocks and knowing a bit about these rocks does not really help you in your life?

Melody: Well, it gets me interested in them and I start collecting them. It just makes me happy to see all of the interesting things that are on rocks. The different colors and all the different shapes and sizes.

Ms. Shapiro: I see. It makes you happy to see all of these things.

Melody: Yes. Mmmm. It gets me interested. A lot of them are really pretty. It's really interesting...I miss our house there.

"These things make me happy," emerged as one of Melody's constructs in the repertory grid conversation regarding the activities of the light unit, and is the first theme to be described in Melody's orientation to science study during this unit. She compares and contrasts these things to the kinds of science learning tht helps in her life.

Melody's Ideas About Ways of Learning Science

Melody's classification of Typical Science Activities grouped by preference appear as follows:

A "The activities which you like the very best

Watch demonstrations by my teacher
Do experiments on my own
Do science worksheets
Do experiments with other kids
Talk about science ideas with other people
Go on field trips
Make science diagrams and drawings
Do science fair projects

B "The activities which you think are just "ok"

Read the textbook
Write reports on science topics
Read library books on science topics

Melody did not give any of the topics a "C" (dislike) rating. When we reviewed her activity groupings, she commented on the second group, "I don't like to read stuff very much, but not that bad, I don't mind it sometimes. I just have a little trouble sometimes...sometimes I don't understand." Throughout my conversations with Melody, she frequently used this phrase, or otherwise conveyed her view of herself as a science learner by saying, "I don't always understand," throughout our conversation over the term. Although I realized that I had heard her express her frustration with a lesson using this phrase quite frequently during the term, a review of the transcripts of our conversations allowed me to see that it was not only in Science that Melody felt that she was not understanding, but in all subject areas. Despite these difficulties in all subject areas, including science, her experience of Science class appears to be a very pleasant one.

Melody says that she does not like to read, even for pleasure, and regards herself as a very poor reader. Though she says that learning science in school "helps me with my life," she also reflects,

> Some of the things we learn are sort of hard to learn. Some things are hard. I can't really understand it, and it's mainly because I can't understand it. Some of the questions that Mr. R. asks us and that, and some of the things we have to do.

Her difficulty with reading may contribute, as it does in Martin's case, to the difficulty which she is experiencing academically. But in contrast to Martin, Melody does not show real interest in understanding the *ideas* which are being presented. Despite the difficulties which she appears to be experiencing, there is clearly a great deal of enjoyment for Melody in the science lesson. When I asked her why she had not placed activities in the category marked "The activities that you don't like" she commented:

> Oh, I really love Science. There's not very much about it that I really don't like. Will you be coming to the science fair? Katherine and I are going to do some kind of experiment with molds, and we, um that's what we saw last year that a sixth grader had done, so that's how we got the idea there. We're gonna set our stuff up, our molds and stuff and everyone will come by and ask us things and stuff.

But Melody did appear more interested in the social interactive experience of the Science Fair than in learning about molds.

6.9.3 Part II: Summary of Melody's Ideas and Feelings About Light and the Study of Light Prior to the Light Unit

Introduction

Melody's views about the nature of light, prior to the study of the topic, are presented in summary form below:

What is Light?

> Light comes from lightbulbs and makes things bright so we can see them? There is also light outside, like the sun and the streetlights sometimes at night. Is that what you mean?

Comment: Melody equates light to its source. She does not explore the idea beyond these statements.

Where is the Light in this Room?

> The light in this room is wherever there isn't darkness or shadows. Like over there in the corner over there, there isn't any light. There's some light here where we are and over by the light up there there's a lot of light.

Comment: Again, Melody associates light with its source. Here she also indicates the reasonable and commonsense view tht light stays predominantly close to its source.

Association of Light Phenomena with Everyday Objects

Melody's associations of light with everyday objects before the study of the topic are presented in Table 6-11.

Comment: Melody checked several items on the list which most of the students in the class did not associate with light. I asked her how she associated light with the following objects: 1. Magnifying glass: "Because you can catch light rays with it sometimes and shine them around." 2. Clothing: Melody described a sequined blouse and a

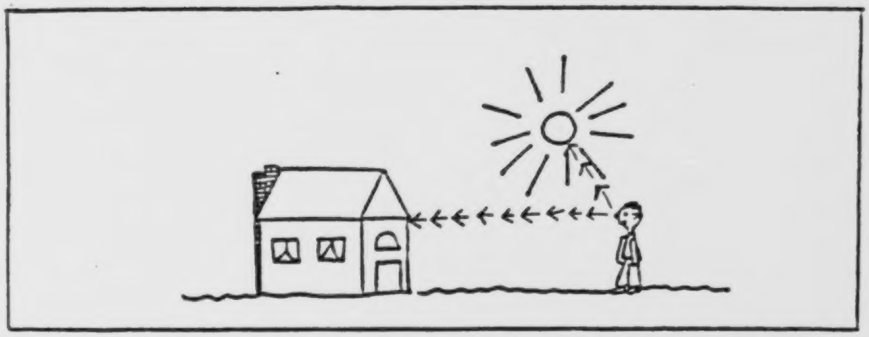
Table 6-11.

MELODY'S ASSOCIATION OF LIGHT WITH EVERYDAY OBJECTS

		Number of Students Checking N=33	Melody's Response
1.	ELECTRICITY	28	+
2.	CAMERA	28	+
3.	TELEVISION	27	+
4.	LASER	27	+
5.	EYES	25	0
6.	RAINBOW	24	+
7.	MIRROR	23	+
8.	STARS	21	+
9.	X-RAY MACHINE	19	+
10.	MOVIES	19	+
11.	FIREFLIES	19	+
12.	PLANTS	12	+
13.	MICROSCOPE	6	0
14.	TELESCOPE	6	+
15.	ROCKS	3	0
16.	BIRDS	2	0
17.	MAGNIFYING GLASS	2	+
18.	PENCIL	1	0
19.	CANDY	1	0
20.	CLOTHING	1	+

metallic-cloth dress which her mother owns that she recalls reflecting light. 3. Plants: Melody comments that plants require light in order to grow. 4. Telescope: Melody recalls going to the Space Sciences Center and viewing sun spots through a telescope. She believes that because the sun is an important source of light, and a telescope is used to look at the sun, then there is a relationship between light and the telescope.

How Does Light Allow Us to See Objects?



The boy sees the light from the sun and that lets him see the house.

Figure 6-11. How Does Light Allow Us to See Objects? Melody's Response

Comment: I asked Melody if the boy actually needed to see the sun itself in order to see the house. She said, "No, because the light rays would shine on it anyway. But the boy would have to be *able* to see the sun because if the sun were not there, he would not be able to see the house."

What Happens When Visible Beams of Light Travel To An Object?

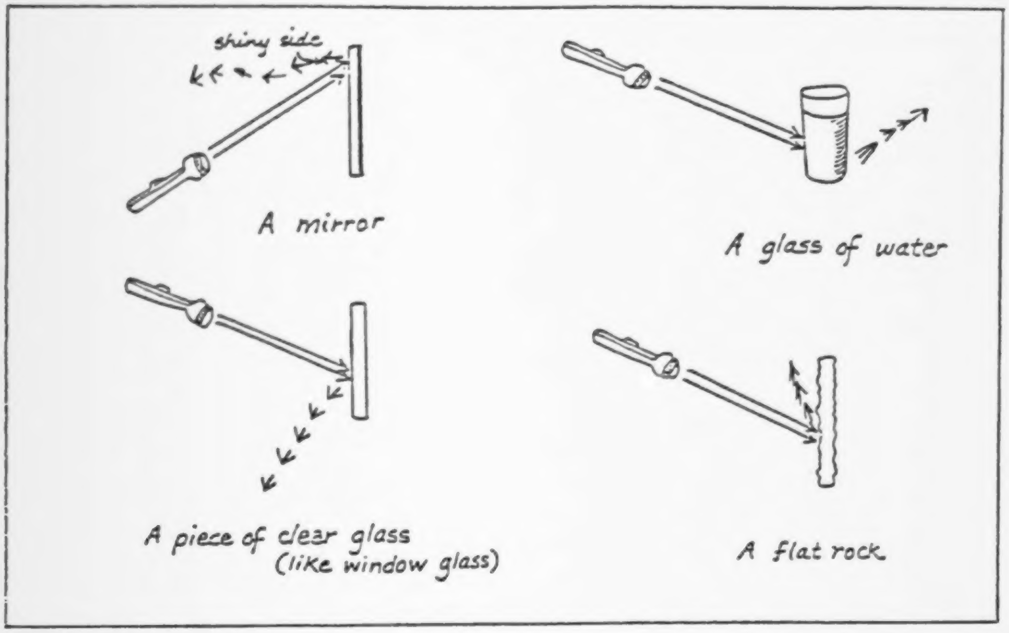


Figure 6-12. What Happens When Visible Beams of Light Travel to An Object? Melody's Response

Comment: Melody's drawings of light reflecting and passing through objects show several different conceptions about light ray reflection. She is the only member of the study group who draws the light rays in the final example reflecting off of the solid, a flat rock. However, she does not show the light rays passing through the window glass. Her idea about light reflecting off the solid rock was not conveyed in the similar example of the boy seeing the house, but, but could be very useful in helping her to develop this concept more fully.

How Do We See Color?

> Colors are all around in everything and we see all the different colors. Like the green leaves and the blue

> sky. We see it all. Um, I don't know how we do that (laughs).

Comment: Melody appears to hold the view that colors are in the object which we are looking at and that the eyes 'somehow' see the colors which are in the objects.

Feelings Associated with Light and the Study of the Topic, Light

> Light, um, it can be really pretty. You know like a really pretty candle. My mom puts a candle in the bathroom and takes a bath and she turns out the light to help her relax. The stars are pretty at night. I um, oh, I like the colored lights. You know like on the Christmas tree. And ours are still on the house. And I like it light when it stays later at night like in summer. Not like now when it gets dark so early.
>
> We studied a little about light in our with our last year's teacher and this year we did stuff with batteries and bulbs? And I liked to work with them, but they were hard to figure out. I didn't likethat very much. It was too hard to figure out. I guess that light will be sort of interesting. We'll learn all about what it can do for you and to you and stuff.

Comment: Melody associates the study of light with the most recent activity which the class was involved with in Science, "Batteries and Bulbs." Although she recalls having some difficulty with the light unit, she shows a fairly positive expectation for the light unit.

6.9.4 Part III: Personal Orientation to Science Learning: Revisiting the Study With Personal Constructs and Emerging Themes -- Paradigmatic Instance of Thought and Action

Melody's Personal Constructs

Melody's personal constructs and ratings of science experiences while learning about the topic, light are presented in the Repertory Grid shown in Table 6-12. Her comments on the factor groupings are presented in Table 6-13.

Three themes emerge through these comments, from my observation in the classroom and through ongoing discussion with Melody. The themes are used to revisit the study and develop the snapshot potrayal of Melody's personal orientation to science learning which guides her as she studies the topic, light.

Emerging Themes in Melody's Personal Orientation To Science Learning

As mentioned previously, the construct, "Things that make me happy." was offered by Melody in the Repertory Grid conversations. This construct along with similar statements and viewpoints is embedded in the first theme to be described in Melody's orientation to science learning.

Her appreciation of the aesthetic qualities of phenomena was also a theme which appeared often in Melody's orientation in the light unit, and in her approach to school life. Melody's completion of the poem, "The Important Thing About...," allows an insight into the ideas that Melody values in the specific topic which she chose to write about, horses. In completing this poem, the children were encouraged to determine their thoughts and

Table 6-12.

MELODY'S PERSONAL CONSTRUCTS

1. Things we do on our own.	555452455244532245155454545445555522425	1. Things that we do with the whole class.
2. Talking about, asking about, hearing about things.	2322222322122432224311121242212254233	2. Just writing things down.
3. Talking about and writing out your worksheet questions	2223344553122222223141233222414234323	3. Experimenting to get the answers to the questions.
4. Getting the answers from the teacher.	2352232222343322113312133222221233243	4. Mr. Don is asking you to give him answers.
5. Getting or giving help from the other kids.	3323232333321344133144411244231342352	5. Not getting help from anyone, having trouble getting it finished.
6. Things that are fun to do, easy.	2221112215343413121111411321131545224	6. Things that are hard to do sort of complicated.
7. Doing things that Mr. Don is telling us to do.	2221423221242441333331222412322454142	7. Doing things that get you into trouble.
8. Things that make me happy.	2221211212111442111211111121123432111	8. Things that upset me.
9. Paying attention.	2123211321221253211211111111111352121	9. Goofing around.
10. Mr. Don is telling us the right answers.	2231333334335333113431335242334434434	10. Talking with kids in your group. Getting answers from other kids.
11. Finding the activity interesting.	3333211322113224223112112411111125111	11. Would rather be doing something else.
12. Mr. Don is talking to us about things.	1321245523322333234432232243313344333	12. We get to look at things with the equipment.
13. You tell people what you think.	2214324343132221221114212343111354111	13. You just keep it inside. You don't tell anyone.
14. Talking about what you think might happen.	4324443422132334332111444355343342324	14. Trying to get the exact right answer.
15. You can't understand what what you're supposed to do.	24314445523222131344444454544554152344	15. You know how to do it.

Table 6-13.

MELODY'S STATEMENT GROUPS

Group 1

Things that are fun to do, easy.
Makes me happy.
Paying attention.

Melody's Statement: When I know to do things and they're not too hard, that makes me happy.

Group 2

Talking about, asking about, hearing about things.
Talking about and writing out your worksheet questions.
Mr. Ryan is talking to us about things.

Melody's Statement: These are things we do when we are talking after the activity. I like to talk about things and hear about things from Mr. Ryan and the other kids. Because I don't always understand -- in science they could, um, it's confusing sometimes.

Group 3

Things that we do with the whole class.
Getting or giving help from or to the other kids.
Talking with kids in your group. Getting answers from other kids.

Melody's Statement: It makes it a lot better I think when you can go to other kids and get help with the answers. I like working with the other kids in my group.

Group 4

Mr. Ryan is asking you to give him the answers.
You tell people what you think.
Talking about what you think might happen.

Melody's Statement: I like to say what I think sometimes, like in all of these you get to do that.

feelings about a topic of their choice. The underlined words represent blanks which Melody filled in in the assignment. Melody's words are underlined in the passage below.

Horses

> The important thing about horses is that they are beautifull. There colorfull. There ridable. There nice. They are fun to play with. But the important thing about horses is they are beautiful.

Theme I: Self Characterization: It makes me happy to learn about all the things in Science. They're all so neat. I like to look at the pretty rocks and flowers around our house. It all gets me interested in science. I like to learn about things that are interesting like that.

Researcher Image/Impression: Aesthetic orientation. Enjoyment of and appreciation of the beauty of natural phenomena.

There is a pattern of unity in Melody's statements and actions are often seen in light of her orientation to focus her attention upon, take particular notice of, and be wide awake to what she finds to be aesthetically pleasing in the lesson. It is clear from reflection on the videotapes and in conversation with Melody that she will not hesitate to set aside an entire lesson to pursue what she finds of immediate interest in pursuing what "makes me happy." When Melody works with other children, however, the strength of this orientation in its full expression, often comes into conflict with others. In the following interaction segment, which was referred to in Martin's case report finds Melody, Martin, and Amy working on activity 6, "Bend that Beam:"

> Melody has reached over to move the light source around.
> Martin: (to Melody) Get outa here Melody!
> Melody: I was trying to fix it. Martin, let me use your magnifier.
> Martin: No. Get outa here. We're trying to do the activity.
> Melody: I just want to use it for a minute. You're supposed to share. (Melody moves the beaker around to create a new effect.)
> Martin: (to Melody) Hey don't! Hey, that's not what we're supposed to do, Melody. Get outa here.
> Melody: I was just fixing it. Oh, oh, look Amy, look inside the light source. OOoooh! Neat! Wow, look!
> Amy: Neat eh? (All of the group members gather around the light source.)
> Melody: It looks likes a pretty little house in there. And it seems, um, it looks like its just grass down there.

Melody has now succeeded in pulling the others away from the task to follow a line of inquiry which she has spontaneously chosen. Although she takes them off the track, each person makes his or her observations about the light which all of the children are sharing. The group then has a discussion about the heat which they feel from the shining light source. This important basic property of light, is actually not mentioned at any point in the light unit.

> Amy: Hey, look. It looks like you can see a little school in there.
> Steven: It looks like peat moss.
> Martin: Oh, it's weird. It's all sorts of little silver things. (Reaches down into the light source) Oh, ouch! Hey! There,

> boy, is that hot! That's really hot! Man, I burned my finger.
> Amy: Yeah. My hand is way out here and it's hot.
> Martin: (Returns to the worksheet) Okay, Steven. Let's draw this. There. I drew mine. (Manipulates the light source) Hey! Look what it does when you move the light beams!

Melody continues to look down into the light source. Martin covers part of the top to alter the angle of the beams which are passing through. He moves the light box away from her.

> Melody: Don't! Oh, Oooooh. It looks like a bug.
> Martin: Whaaaat? (Loudly) Who cares? Go away Melody. Get outa here. Do what you're supposed to do. Okay, okay what's this word, Steve?
> Amy: (Has been working alone, but has been listening to Martin and Melody). Particular dummo. You're supposed to see where it crosses and put it on the sheet.

Melody's interest in the aesthetic and her attempt to draw the other students in the group into thinking about the attractive aspects of the materials is of particular annoyance to Martin who is interested participating in accomplishing the tasks set. Melody was also effective in pulling Amy away. Amy is usually more dominantly task oriented, (Case Report V) but she also is drawn to the aesthetic qualities of the phenomena in her pursuit of meaning.

Melody and I watched the videotapes of her pervasive and persistent "off task" behavior as she worked in the small group. As she watches herself on the videotape, she appears unconcerned with her continual "off task" behavior. As she watches the videotapes with me, she observes Mr. Ryan reprimanding her on several occasions for not pursuing the task required, but not once did she appear embarrassed, either on tape or in conversation. On these occasions she does not comment on her own "misbehavior." As I reviewed my conversations with her, I noted that her comments fell into three categories: 1) References to the fact that she was not understanding what she was supposed to do during the lesson, 2) Statements about what she found to be immediately interesting about the lesson, or 3) Comments concerning what another person in the class is doing. From our conversation and her actions, it appeared that Melody was unaffected by Mr. Ryan's reprimands concerning her off-task behavior. Except for the somewhat jolting, momentary redirections to task, his remarks to her had no real lasting effect upon her 'delinquencies.' Her consistent comment was, however, that she was not understanding what she was supposed to do in her lessons. It seemed almost as if she, herself, did not consider it her responsibility to know what she was supposed to do in the lessons. Melody's difficulties and behavior appeared to be a mystery to her teachers and to me thoughout the unit. Exploring and delineating Melody's behavior and orientations became immensely interesting to me, as I began to observe and understand the pattern in thought and action of this student who seemed so very bright and articulate, and yet who performed so poorly in nearly all of her academic work. Melody was a mystery to her teachers, to me, and it seemed, in many important ways to herself.

During the interaction segment transcribed above, all of the children were temporarily led "off task," by Melody. They were participating in their own ad hoc "messing about" session. Science educator/philosopher David Hawkins (1962) eloquently advocated "a messing about period" as a prelude to the development of concepts in science. In fact, at the initial instigation of Melody, the children in this sequence were brought into direct contact with one of the most basic and directly observable qualities of light, heat. This very basic characteristic of light was not mentioned in the curriculum as the unit, "Light," focussed upon the reflective and refractive qualities of light only. This unit might have better been given the title, "Reflection and Refraction."

An observer with a different perspective, watching this transcript segment, might see it as an example of "goofing around," "off task" or "wasting time." But if we analyze the transcripts to understand how students are constructing meaning through their personal orientations to science learning, we can see how each person lives out and practices his or her own personal orientation within the small group interaction. Given the freedom to do so, although in this case, it was simply taken, the students made discoveries about light and shared them with one another. This behavior is often misinterpreted or is not valued by the teacher and is often punished in the classroom, as it conflicts with the tasks and goals set and stated by the curriculum and by the teacher.

Mr. Ryan remarked candidly to me that throughout the year, he had experienced difficulty understanding Melody. He observed some of my videotape test sequences at the beginning of my visit with the class. In one lesson which we watched, Melody was seen sitting near the teacher as he explained a mathematics problem. As Mr. Ryan spoke, Melody fondled a "Care Bear" and communicated nonverbally with a student at the next table. Mr. Ryan remarked to me as we watched the tape:

> I spoke to Melody there about listening. She's a hard person to understand. I don't know what it is that she does, but I, don't know, I find what she does _very_ annoying, somehow.

The elements of Melody's personal orientation to learning in the classroom and her orientation to the science lesson were unknown to Mr. Ryan. When I first began to talk with Melody, I also found that, on occasion, I was feeling slightly annoyed by Melody's actions. I wondered about about her reasons for so frequently changing to move away from the task at hand or the ways by which she would change the direction of our conversation or hop around from subject to subject. The understandings of the childrens' orientations to science learning took much conversation, observation and reflection. But when I began to understand some of the anticipations and expectations which Melody had for science class, I realized how these clearly placed her in an annoyance collision course not only with her teacher but with fellow students. The potential for an awareness by teachers and students of personal orientation to science learning became more evident in Melody's case. Melody would benefit greatly by becoming more aware of her own approach to learning and taking greater responsibility for her own learning. I also came to appreciate that Melody possessed very great gifts and talents in her insight into the social dynamics of the classroom setting, which actually helped her to grasp some of the scientific ideas about the nature of light which were being presented in the classroom. Melody's second theme demonstrated that she had very little knowledge of her own skills and talents. She repeatedly demonstrated a view of herself as never quite understanding what she was "supposed to be doing."

Theme II: Self Characterization - It's better when you can work with the other kids in your group and go to them to get help and answers. It's better than working alone because I don't always understand what Mr. Ryan wants.

Researcher Image/Impression: Anticipates that she usually does not understand science concepts nor what she is "supposed to do" in science.

A pattern which emerged in conversation with Melody showed her consistently approaching her studies with the view the she was poorly informed about what she was supposed to do.

During the activity, "Hit the Target," the students were given the task of discovering several different ways to reflect light beams around a book. Melody and I observed the videotape together. I asked her before we reviewed the lesson if she would be able to tell me what she thought was the main purpose of the lesson.

Melody: Well, it was sort of an okay activity. It was sort of fun to see how you could make the light do what you wanted it to do and all. But I couldn't figure out what he meant by this mark that he made here (part of the diagram on the worksheet). I didn't know what he meant by that. I didn't know if you draw it in or what. And he explained it, but I didn't understand it.

Ms. Shapiro: I see. So before you were even starting on the lesson you didn't understand what to do?

Melody: No. In this part he is coming over.

> Melody's group is attempting to determine how to perform the tasks on the worksheet.
>
> Melody: (peeling the backing off of the mirror) Oh, this looks neat.
>
> Amy: You shouldn't do that. You're not supposed to do that.
>
> Melody is sitting away from while the others are working on the activity. Mr. Ryan comes over to the group. He says

> nothing, but looks directly at Melody who is still peeling the backing off of her mirror. He is obviously annoyed with Melody, but she does not seem aware that she is doing anything "wrong."
>
> Melody: (Smiles at Mr. Ryan). Look, Mr. Ryan, lookit the back of this mirror.
> Mr. Ryan: Now is that what you're supposed to be doing?
> Melody: Well, I'm working with them. We're doing...this..I'm getting this...
> Mr. Ryan: (Points to Melody) Do what your're supposed to be doing...NOW! (He walks away)

Ms. Shapiro: Did Mr. Ryan help you to get back on track there?
Melody: Not really. He came over and just sort of looked at me. He just sort of looked at me and everybody and we was wondering what we were supposed to be doing.
Ms. Shapiro: So that didn't help you understand a little bit more of what you were to do as you worked through?
Melody: No. Um, I um didn't even know what to do. Amy and Steven helped me, they showed me like they did the experiment thing, like Amy especially on what to do and we were supposed to try and that and we were supposed to put a book here and then um put a mirror and we were supposed to draw in where we put the mirror here and show where it went. But I could just here, um, I got it figured out because I could just watch what the other people make, put the book in place, like that. I just put down then when where I thought, there, about how the light went about where I seen the light go. They did it and so I could just watch and just write down where I seen it go.
Ms. Shapiro: I see, you didn't actually do this yourself?
Melody: No.
Ms. Shapiro: Can you show me how you understand how the light might be reflected around the book?

Melody showed me three arrangements of the light source and mirror which would very effectively move the beams around the book. Most of the students had been able to suggest one arrangement. Melody had employed two mirrors in one of her sketches which had not been one of the suggestions made by members of her group. This was quite an original use of the materials which she had been given. Although Melody had not held the scientist's viewpoint regarding the reflection of nonvisible light rays prior to the unit, there were several ideas which she had indicated on the diagrams depicting light beam interaction with translucent and opaque objects which were very different from her peers and which contained elements of the scientists' viewpoint.

Ms. Shapiro: These are very good ideas. Did you have some help with these?
Melody: Well, this one is the one we all had as a group, and this one is just like it only turned around sort of. I seen the group in the loft doing this one. They had it the other way than us. This one is one...one that I did with Amy.
Ms. Shapiro: But Amy didn't put this one on her sheet did she?
Melody: No. It was sort of my idea. She didn't like it.
Ms. Shapiro: Did you finish the worksheet here?
Melody: I didn't have enough time. I liked experimenting with it. I began to understand when I seen them putting the book in place and that and that's when I began to understand what I was supposed to do. But he confused me by where he put the little question marks and here just a little line I didn't understand what he meant, so I thought it was a pencil -- doesn't that look like a pencil?
Ms. Shapiro: Yes, it does. You mean that Mr. Ryan confused you?
Melody: Yeah.
Ms. Shapiro: Didn't Mr. Ryan tell you what the symbols meant before the activity?
Melody: Oh, maybe. I don't remember.

Melody referred to the worksheet which Mr. Ryan had explained to the class. She remarked that she found "what Mr. Ryan had written and drawn on the worksheet" very confusing. Though Melody frequently points out in conversation with me that she does not understand what to do, or the material, I did not once observe her ask Mr. Ryan for help or tell him that she did not understand what she was supposed to do.

I asked Melody how she finally did discover what was to be done for the lesson, and how she believed that she had determined were the best approaches to reflecting the light beams around the book.

Melody: I seen what the other kids do. But only I seen the others do, um use a book and I thought, it was, even then, I thought it was a pencil shadow. (During the previous lesson symbols were presented for the students to use in reporting their results on the worksheet. Melody is telling here how she initially confused the pencil shadow symbol for the book symbol on the worksheet.)
Ms. Shapiro: So, did you finally clarify these two symbols? worksheet up?
Melody: Well, it took a while. But, oh, yeah. Because my friends are there to help me.
Ms. Shapiro: Was there anything else confusing to you? Were the directions easy to understand?
Melody: I don't really read them. I just work with the other kids and watch the other kids and we get the answers together. Sometimes I get the ideas from the other groups. But in this lesson, I like working with Amy the best. She always gets the answers. She's in my group this time and we did this...

It is clear that Melody has a view of herself as one who usually does not have an understanding of science lessons. I observed a part of Melody's living out of this expectation pattern of watching along with the other students as they worked through the details of each lesson.

She consistently copied from their worksheets during the lesson. Several of the students have complained that Melody copies from their worksheets during the lesson. The practice was not strictly prohibited by Mr. Ryan, as the children are encouraged to work together, but Melody's approach was obviously not in the spirit of Mr. Ryan's intentions. Melody's habit of copying answers was an important major strategy in her efforts to complete the required worksheets. As she herself stated, she copies from Amy most frequently. Amy objects to this, complains to Melody, and quite often to me during our discussions. What appears hidden from Melody, her peers and her teacher is that she has very creative and useful ideas of her own, and is able to grasp the intent of directions and pursue her own ideas about solutions to the activities.

Melody's belief that she does not grasp ideas and her difficulties with reading the worksheet interweave with her great interest in the social relationships within the classroom. She persistently engages fellow students in helping her to understand what to do, and frequently visits other groups to find out how they are solving the tasks and problems assigned to the class.

During an activity entitled, "Lenses and Lightbeams," Melody was annoying all of the members of her group. Finally Mark, who was intently working with the materials, left to complain to Mr. Ryan. As he left, Amy also left for a few moments. Melody turned Amy's worksheet around and copied down her answers. As she did this, Mr. Ryan came to her table, placed both his hands down in front of her and asked:

> Mr. Ryan: Are you doing what you're supposed to be doing?
> Amy: (Returning to her seat) *I* was.
> Melody: I'm just getting some help from Amy.
> Mr. Ryan: (to Melody) What has splashing around water got to do with what you're supposed to be doing? I want you to get down to what you're *supposed* to be doing *right now*. Do you understand?
> Melody: Yes.

Ms. Shapiro: What were you supposed to be doing?
Melody: Well, it was too hard to figure out.
Ms. Shapiro: I see.
Melody: There was something that you were supposed to see in the beaker, but nobody understood. (Laughs) I got Amy to help me. I didn't want to ask Mr. Ryan. He was mad. Donnie's group was doing it and I went over to them and seen what they were doing. But Mr. Ryan told me to sit down. We were supposed to take this word "LIGHT" and predict what you *think* will happen. That's what I did. I predicted. Then I didn't know if I was supposed to also put the pencil in the water or what, so nobody would tell me or anything so I put it in the water.
Ms. Shapiro: And then you splashed Dean with it?
Melody: Yes. (laughs)
Ms. Shapiro: Let's look at that part again.

> Melody: Whose desk am I sitting at?
> Steven: (reading) Test your prediction...
> Melody: (To group) Do you put that in the water? (No response) Do you put that in the water? (No response from group. Melody puts her pencil in the water.) Amy look, this is neat! The pencil gets small. (Amy is writing. No response) Melody splashes Mark with water and laughs.
> Mark: Hey, cut it, hey stop it. (Leaves the table and returns with Mr. Ryan)

Melody: That's where Mr. Ryan came over and talked to me.

Ms. Shapiro: What were you supposed to be doing?

Melody: I don't know. But it had to do with the little piece of paper and how it looked on the other side of the beaker. It was um, nobody understood. We looked and it was just blurry. So I put the pencil in the water, that's all.

Ms. Shapiro: Were you, um disrupting here, do you think?

Melody: No. Not really. Mark wasn't sure what to do either. We didn't understand what we were supposed to do. When we put the paper up to the beaker it was all blurry. Mark was asking Steven to help him. He went down to the front of the room and where kids were looking at the beaker through a beam of light. And he saw that the beams were doing something like twisting when they went through the water. Mr. Ryan was working there, on the floor with him. And I went up to the loft to see the other guys doing stuff, and they were using a measurer, and they found out that at one place on the meter stick the word was doing something like changing or something, but I don't think that's what Mr. Ryan wanted. I, was looking and stuff, but he just gets mad sometimes but I didn't understand what it was, what I was supposed to do, and when we can't figure out what we're supposed to do. And he just got mad. He didn't explain or anything.

Theme III: Self Characterization: Science is so much fun. There really isn't anything about it that I don't like. I like to work in groups best because your friends are there to help you and you get to work with things and talk to people in the other groups to see how they did it, how they do it.

Researcher Image/Impression: Social interest and insight. An aware socialite.
The special meaning of learning science is, for

Evident throughout Melody's case report is the value she gives to social interaction in the classroom, and the help that she gets from the other students. She showed a keen awareness of what other students are doing during the lesson and what was known about the lesson by other students. In fact she frequently leaves her group to find out what other students are doing and thinking about the lesson. The third theme in Melody's orientation to science learning embraces, values and gives attention to the social interactions within the classroom.

This theme is similar to Martin's Theme III, in that both Martin and Melody value the social interaction during group work in science. Both students commented that they find the help which others give to them to be essential in the carrying out of their responsibilities and tasks as students in Science. Melody, however, appears to be more dependent on others to provide her with the answers to questions, as she rarely works out what is to be done for herself, nor does she always do the tasks at hand. Martin needs the help of other students to find out what to do, but he fully participates in the activity, is interested in finding out for himself what to do, and writes in his own answers. In his interactions with the other students, it seems important to him to be demonstrating his abilities to peers and to the teacher. Melody, however, is more interested in social engagement with her fellow students. Her approach to knowing in Science is built upon developing an awareness of what they are doing, what they are thinking, and what they are finding out. Melody has a remarkable awareness of the social life of the classroom. She is continually moving about the classroom, going from group to group to determine what the various groups are doing.

Though Melody does not seem to be aware that she disrupts regularly when she does not understand the nature of the task she is undertaking and pursues her own interests, she does demonstrate a remarkable awareness of what others in the class are doing and how they are thinking about the phenomena. Mr. Ryan is not aware of Melody's insights in this area, and she does not inform him of them. The pattern of Melody's thought and action which emerges in Melody's orientation to science learning conflicts with the formal/instruction orientation which she is working in in the classroom science learning environment. She has such great difficulty with the worksheets and so little interest in the major questions posed by the worksheets that her dominant interest in classroom social interaction takes her attention here.

Through her social interaction orientation, Melody has a heightened awareness of the other children in the group, what others in the classroom are doing, and what answers they are coming up with. It appears that in this way, Melody has gained a real grasp of the overall activity and how it is being understood by the classroom community. In this way, it is not despite her habit of playing with the equipment and socializing that she is grasping ideas, but it seems that it is because of these behaviors that she has been able to put ideas together without reading the directions or trying to figure out what is to be done on her own. For in the end, it appears that it was because of Melody's social interaction participation orientation that she actually did show some grasp of the ideas in the light unit at a later time.

Melody's third theme also reflects her sincere interest in participating in some way in the science lesson, and in expressing her viewpoint. She has many creative ideas and explanations and likes to share these with members of her group. Though her ideas are sometimes not relevant to the lessons on which the student are working, she often has a viewpoint which is relevant, but which she often does not have the confidence to pursue. Social interaction in Science class seems, for Melody, to be a very meaningful aspect of her experience. The opportunities and encouragement for this type of contribution and clarification where understanding is weak have been few during light lessons.

Though Melody shows consistently that she is not aware that the patterns in her own approach and orientation to science learning which often lead to reprimand, neither is Mr. Ryan aware of what is most meaningful to Melody during the science lessons. The possibilities in benefits of understanding will be for Melody, in terms of her taking greater responsibility for her own learning. For Mr. Ryan, there is considerable potential gain in understanding the variety of orientations which guide students in their science learning and in understanding what is of meaning and value to the students as they work at the task of learning science.

Melody does have some insight into the ways that she learns best which reflect her social interest:

> I like to talk about things with the other kids and with Mr. Ryan, like I like to listen to him tell us things. That really helps me to get a better understanding. I like to say the answers sometimes. He sometimes asks me to say the answers.

I asked Melody about her interpretation of the activity in which the pencil appears broken in the beaker of water. We watched the videotape of the activity, and before we reviewed the discussion, I asked Melody what her explanation was for the unusual look of the pencil in the beaker of water.

Melody: Well, I got to say that I thought it happened because the water makes things look bigger and also because of the angle of the beaker. It's round and it makes the water look larger.
Ms. Shapiro: How does the water make things look larger?
Melody: I'm not sure. It makes things look bigger.
Ms. Shapiro: There was some discussion about this after the lesson.
Melody: Mark had the right answer. Mr. Ryan said so.
Ms. Shapiro: Do you recall what that was?
Melody: He said that light rays come from the pencil and bend or something. I wrote that down.
Ms. Shapiro: Is that correct?
Melody: (Laughs) Yes! Mr. Ryan said so.
Ms. Shapiro: So you accept this as correct.

Melody: Well, no. It's sort of hard to understand that. It doesn't, well, I can't figure that one out very well. Other people had trouble too. Like Nathan, (laughs) He even yelled out from the loft, "Light rays come from pencils?"

Ms. Shapiro: Here is the worksheet you were working on in this lesson. Let's look at this.
Melody: Oh, yeah, you keep all of the copies don't you. Do you have everyone's?
Ms. Shapiro: I have a sheet from everyone in our discussion group.
Melody: Oh, um from Martin and Amy, um Pierre, Mark and Donnie?
Ms. Shapiro: Yes.
Melody: What did Michael say? Did you get Michael's too?
Ms. Shapiro: Well, let's look at your sheet before we look at what the other kids were saying. Let's be clear about what you were thinking. Can you tell me what you put there and what you were thinking? What was your answer to the question?
Melody: (Reads) When the pencil is closer to you it looks skinny. When it is close to the wall, it looks fat. That's what Amy and I put. (Laughs) (Melody had actually copied Amy's paper.) But I don't know what the right answer was. I think that they say it on the videotape.
Ms. Shapiro: Shall we watch it?

> Mr. Ryan: When you looked at the beaker what did you see--hands up!

Melody: Oh, yeah, in this part, Pierre gave an answer and I was thinking that he had the same idea as me. If you're wondering about my lipstick, Diane's been putting lipstick on us and it's that crayola stuff. (Laughs) My lips look blue! She gave me some just before Science. Oh. Mr. Ryan is asking what was happening and everyone is talking about what was happening to the pencil. Then he asked for a reason why.
Ms. Shapiro: I see. Did anyone have an explanation?
Melody: I think they did, but I don't think anybody had the right answer. Just that the pencil looked broken and the water made it look broken, er um, bigger. That's all I remember. Sam said the water acts as a magnifying glass and I, I thought that that was a good answer. And Donnie said that maybe it was the water and the glass together. I thought that

that was a good answer because the water and the glass, they work when you make it look larger.
Ms. Shapiro: How do they do this?
Melody: It's in a circle. And it's coming forward, where the circle part comes forward does it. It leans this way and so it makes it look bigger. When you look at it. That's what I said there. (points to videotape) And I was saying that that might be the reason why it looked bigger, I wasn't sure or anything. But it um, could have could be why. So I said that. But I don't think (laughs) I don't think so...
Ms. Shapiro: No? What do you think?
Melody: No. I don't know why it does that. But it could be this circle thing because me and Amy were talking about it and trying to figure it out and that's what it did. That's what we decided.
Ms. Shapiro: You don't think that your answer is as possible as any of the others?
Melody: No. Probably not. Well,...but what I'm saying could be right. It's just an idea. I don't know or anything. It's just what I seen and what I think. So it could be. Could be.
Ms. Shapiro: How would you know for sure?
Melody: Wait till Mr. Ryan gives us the right answers.
Ms. Shapiro: Then you know for sure?
Melody: Well, usually I'm not right anyway.

Melody is aware of the other students' contributions and thinking as they learn about light, but has very little understanding of her own great talent in being wide awake and attentive to these ideas.

6.10 CASE REPORT V: AMY

6.10.1 Some Initial Observations and Impressions

The children are involved in the activity portion of their lesson on prisms. Amy leans quietly over her worksheet amidst a background of cheerful chatter and bustling activity. She turns and carefully checks the angle of the light shining through the glass prism set in front of her, then looks behind her to a wall chart, which diagrams the range of colors in a white light spectrum. She opens an immaculately organized pencil box and selects a colored felt pen. Again she leans forward close to her paper and painstakingly colors in the beams she has drawn, checking frequently with the wall chart.

There is movement all around Amy. She works intensely, quietly, in a concentrated manner. Louise bounces over to her, leans an elbow on the table, and looks at Amy's drawing. "Can I borrow your ruler?" Without lifting her eyes, Amy responds, as if to her paper, "Pauline has it." Louise rushes off to find Pauline.

Melody sits down at the desk next to Amy. Amy continues working quietly, methodically coloring in each beam in the spectrum. Using a black pen, she outlines each color individually. Amy asks Melody, "Those guys have the same as us?" Melody nods and begins to color her own worksheet.

This snapshot of Amy working is a typical portrayal of her style of involvement throughout the science unit. My initial impression of Amy is that she is a person with an unusually strong commitment to task. To observe Amy's involvement in Science is to consistently see her working very hard to determine the task required in a lesson, then she commands all of her resources to accomplish the task set before her.

6.10.2 Part I.: Thoughts and Feelings About Learning School Science

Amy's Ideas About Ways of Learning Science

Science is not Amy's favorite subject. Still, she checked the second highest category, "I like it," when asked, "How do you feel about learning science in school?" Amy told me that she often found that "some of the ideas in Science are very difficult to learn," but that in many ways "Science is very fun, particularly when you get to do things with the materials." When I asked Amy if she liked to do science activities at home or read about science, she said, "No, not at all. It's not something I'm really interested in outside of school." Though Amy has lived in Canada since the age of four, when she began Kindergarten, English was not the language spoken in her home. Amy also spoke to me about many family responsibilities which made demands on her time. She explained, "I take care of my brothers and sisters at home and that takes a lot of time, so I don't do a lot of things like that." [Science activities]

When I asked Mr. Ryan what he knew of Amy's background, he realized that he was able to share very little beyond her in-class performance. Mr. Ryan was not aware that Punjabi was the language of the home, nor was he aware of Amy's extensive home commitments. Mr. Ryan knew Amy as one of "the top students, perhaps the highest achieving student in the class."

Amy's classification of Typical Science Activities, grouped by preference appeared as follows:

A "The activities which you like the very best"

Do experiments with other kids
Go on field trips
Make science diagrams and drawings
Do science fair projects

B "The activities which you think are just "ok"

Do experiments on my own
Do science worksheets
Talk about science ideas with other people

C "The activities that you don't like"

Read the textbook
Watch demonstrations by the teacher
Write reports on science topics

I shared these groupings with Amy and asked asked her if she considered there to be any sort of pattern in her groupings.

Amy: Well, I really hate the part here where you just read the textbook and write boring reports. I like doing neat projects with things, though.
Ms. Shapiro: You've also put "Watch demonstrations by the teacher" here (pointing to the "don't like" category.
Amy: Oh, when he goes over things like before we do the activity? I just start thinking of other things, like I... what I want to do and things.
Ms. Shapiro: So you don't find that particularly interesting?
Amy: It's really boring. And when, like at the end of the activity, like when we go over the worksheet, and you have to go over everything, describing everything to the whole class, well, it's really boring.
Ms. Shapiro: Is it the listening that you don't like, or-
Amy: I just usually figure out what to do, so it's just repetition.
Ms. Shapiro: You place working with other kids in a higher preference category than working alone here.
Amy: Yeah. It's much more, well usually it's very fun to talk to other kids to find things out and do things like try to find out the answers with other kids helping. I like that better than just doing things alone. Because there's no one to talk to to share things out.

Amy rated Science as "fairly easy" on the survey form given to all members of the class. She pointed to this statement as she remarked, "Sometimes there is too much to learn. I just don't like it when you have all these little details to memorize and stuff."

Despite the fact that Amy spoke of disliking the memorization of "all of the little details," it is very clear through working with and talking with her, that she takes the responsibility for learning these details very seriously. Her conversation and personal constructs focus upon the tasks of learning and the logistics of completing the tasks at hand. Amy did not refer to the science content of lessons as of particular interest during our discussions. Amy was more concerned with and spoke of the accomplishment of tasks. Through discussion with her, and during attempts to explore how she put ideas together, it appeared that Amy made no spontaneous effort to connect ideas from previous lessons in the ways that I had observed Mark, Martin, and Donnie striving to do. Amy worked systematically, taking each task one at a time, doing each question as it was set before her. It appeared that Amy might benefit from a greater awareness of the ways that ideas from previous lessons were being built upon and were connected to the development of later ideas.

6.10.3 Part II: Summary of Amy's Ideas and Feelings About Light and the Study of Light Prior to the Unit

Introduction

Amy's views about the nature of light and her feelings about the study of the topic are presented in summary form below.

What is Light?

> I really don't know. It helps you see. It's from bulbs and the stars and the sun. I think it's important to study because we use it at school and like in our homes.

Comment: Amy, like Mark, is aware that she does not know exactly what light *is*. Without being asked, she offers reasons why she believes the topic should be studied in school.

Where is the Light?

> The light in this room is in the lights overhead and in the most parts of this room except where there are things that are dark.

Comment: Amy states that she believes that light is "in" its source, a commonly offered commonsense viewpoint. She states that where there are dark areas in the room there is no light present.

Association of Light Phenomena With Everyday Objects

Amy's association of light phenomena with everyday objects are listed in Table 6-14.

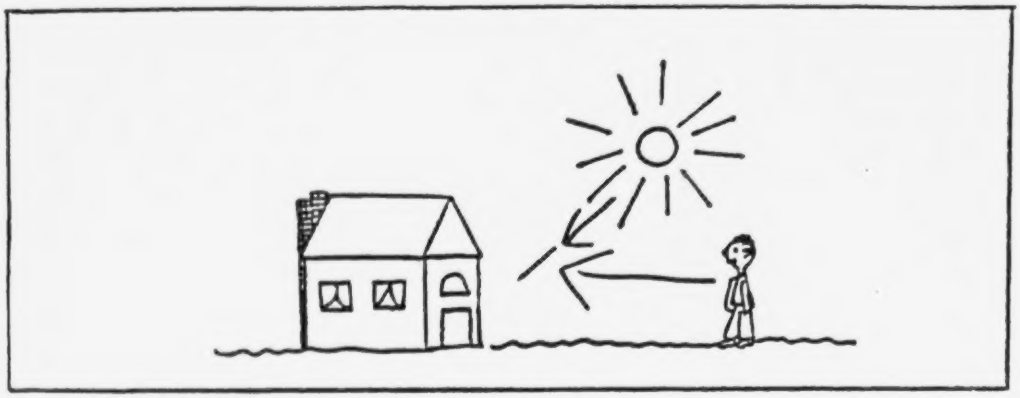
Comment: Amy's profile of association of light with everyday objects is fairly typical of the responses put forward by other class members. Amy mentioned, as did several other students, that she had never seen a firefly, and therefore did not associate it with light.

Table 6-14.

AMY'S ASSOCIATION OF LIGHT WITH EVERYDAY OBJECTS

		Number of Students Checking N=33	Amy's Response
1.	ELECTRICITY	28	+
2.	CAMERA	28	+
3.	TELEVISION	27	+
4.	LASER	27	+
5.	EYES	25	+
6.	RAINBOW	24	+
7.	MIRROR	23	+
8.	STARS	21	+
9.	X-RAY MACHINE	19	+
10.	MOVIES	19	+
11.	FIREFLIES	19	0
12.	PLANTS	12	+
13.	MICROSCOPE	6	0
14.	TELESCOPE	6	0
15.	ROCKS	3	0
16.	BIRDS	2	0
17.	MAGNIFYING GLASS	2	0
18.	PENCIL	1	0
19.	CANDY	1	0
20.	CLOTHING	1	0

How Does Light Allow Us to See Objects?



Light falls on the boy and is...shines on the house. Here the boy is looking at the house.

Figure 6-13. How Does Light Allow Us to See Objects? Amy's Response

Comment: Amy considers the light and the house entirely from the perspective or point of view of the boy in the drawing. The arrows which she has drawn in reflect this view.

What Happens When Visible Beams of Light Travel to An Object?

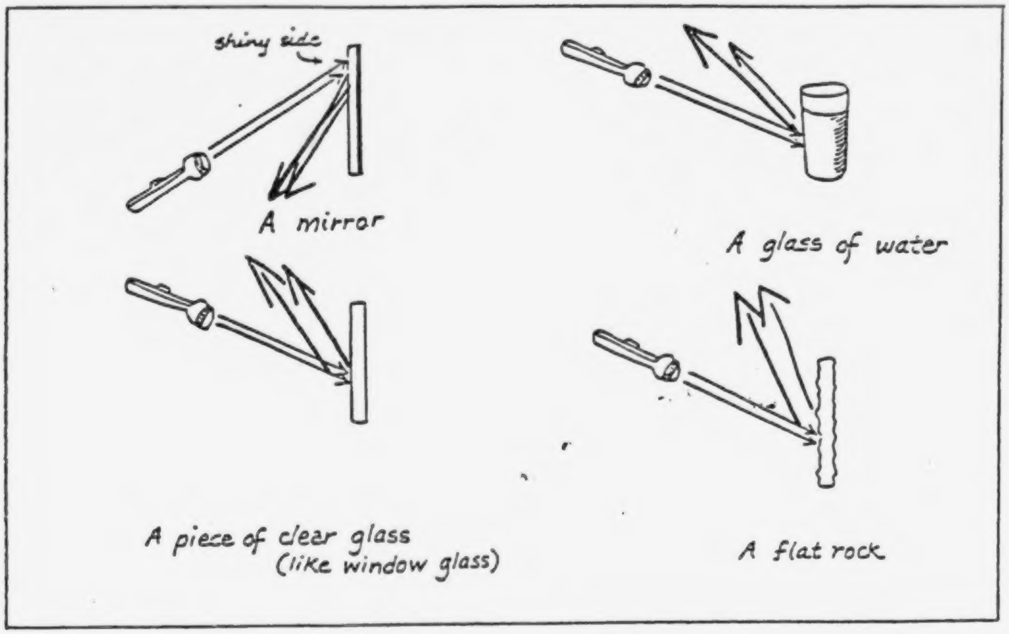

shiny side
A mirror
A glass of water
A piece of clear glass
(like window glass)
A flat rock

Figure 6-14. What Happens When Visible Beams of Light Travel to an Object? Amy's Response

Comment: In each diagram which Amy has drawn, she has shown light reflecting off all the objects preented ot her. Light beams are not shown passing through the clear glass nor through the glass of water. Her portrayal of light rays reflecting off the flat rock is consistent with the scientist's view of light beam reflection. However, in conversation with Amy regarding this diagram, she commented that the light would only reflect if the rock were "shiny enough." Light beams would not reflect from a non-shiny surface, for example, a hand or a person.

How Do We See Color?

> We see the color with our eyes. We see, like if something's been dyed red, we see the red dye in it, or we see the bits of yellow like in your sweater.

Comment: Amy states that the dye color which is in the object is what is seen by the observer. This view has been the most commonly stated by Amy's fellow class members, with some exceptions, although it is not the scientist's explanation of human ability to see color.

Feelings Associated With Light and the Study of the Topic Topic Light

> Well, I guess I'd say that I like it. It lets you see. I hate the darkness, the dark, so I guess I do like light. (laughs) I never really thought about it, though...Umm. Some light can be too bright and I don't like that I guess. I've never read about it or studied light before. I don't know anything about what we'll learn. I don't think that it sounds very interesting.

Comment: It appeared that Amy had no real interest in her prior experiences in the study of light phenomena and does not anticipate that the topic will present a particularly interesting unit of study.

Part III: Amy's Personal Orientation to Science Learning: Revisiting the Study with Personal Constructs and Emerging Themes--Paradigmatic Instances of Thought and Action

Amy's Personal Constructs

Melody's personal constructs and ratings of science experiences while learning about the topic light are presented in the Repertory Grid shown in Table 6-15. Her comments on the factor groupings are presented in Table 6-16.

Emerging Themes In Amy's Personal Orientation to Science Learning

Two themes emerge from the variety of approaches to data analysis. Amy's commitment to a task orientation is clearly a dominating theme for all of her work in the classroom. Amy is unusually resourceful in determining what is to be done, then accomplishing the task. She is recognized as a highly successful student by her teacher and her peers. It is noteable however, that Amy has little interest in the topic of study for its own sake, and at the end of the unit, although she placed the correct answers on the worksheets, Amy emerged with little understanding of the nature of light.

Table 6-15.

AMY'S PERSONAL CONSTRUCTS

1.	Experimenting with things.	4252112112442332541242434424121323125	1.	Writing things down and answering questions.
2.	You get it. You understand it.	2115333335543555332453153455332515152	2.	You don't understand anything.
3.	You're trying to get the answers. You're working to figure things out.	5152232245525152352255523351244351552	3.	You're just correcting your work.
4.	You're speaking up in class, giving your answers.	5315433443245355332253533453224355352	4.	You're listening to others' ideas.
5.	Paying attention.	2251322221122555322321313551221511153	5.	Goofing around.
6.	You're doing it.	4511333335533555332244251355224523132	6.	Someone else is doing it for you.
7.	Doing something fun.	2232122213332342333233332333222355143	7.	Doing something boring.
8.	Working hard to learn.	2535555555535335225235134432534551524	8.	Working in a fun way to learn.
9.	Just talking about ideas.	5512555551152514553355455543533512322	9.	Doing something.
10.	Getting ideas from listening to other people.	2312453531534323223422113331253212335	10.	Asking questions of your own.
11.	You need to get some help.	3352333331135123322432324221242113513	11.	You're able to help someone else.
12.	You're talking to others to find things out.	3325333322542555344222313453323555253	12.	You're alone and not understanding.
13.	Experimenting with other kids.	4255335225545332541225453455141315145	13.	Spending the time getting the worksheet done.
14.	Like the activity.	4333122224443353332434232543222355143	14.	Hate it. I don't like working with it at all.
15.	Learning big ideas.	5125333425552551341312253555232555151	15.	Too many details to learn. Too many little things to learn.

Table 6-16.

AMY'S STATEMENT GROUPS

Group 1:

You get it. You understand it.
You're doing it.
You're able to help someone else.
You're learning big ideas.

Amy's Statement: You get it and understand it and it's interesting. Not a whole bunch of little details. Then you can help somebody else to do their work.

Group 2:

Experimenting with things.
Working in a fun way to learn.
Experimenting with other kids.

Amy's Statement: Working with other kids and doing experiments is a fun way to learn.

Group 3:

You're trying to get the answers. You're working to figure things out.
Doing something fun.
Getting to do something.
Like the activity.

Amy's Statement: Doing things is a lot more fun way to learn than just listening.

Group 4:

Paying attention. Listening.
You're talking to others to find things out.

Amy's statement: You're talking and listening to other kids to learn.

Theme I: Self Characterization: My job in Science is to figure out what to do. When you get it, and you understand it. If it's interesting to you, then you learn it better. I don't like a whole bunch of little details in Science. There's sometimes just too many little details to learn.

Researcher Image/Impression: A task orientation.

The Responsibility to Do Well

Throughout my review of videotapes with Amy, during our conversations, following an examination of clusters of constructs, and throughout discussions with others in small groups, I noted that Amy spoke of and portrayed a commitment to the responsibility of being a student. Amy speaks of the importance of "the work we do to learn in school." She talks about her approach as one of "figuring out what needs to be done on the worksheet" and then doing it. In small group work, she regularly directs the group to the task at hand. Students often go to Amy when they want to find out what is required on a worksheet, for she can be counted on to be extremely resourceful in her attempt to grasp what is required in the lesson.

The importance to Amy of completing the task causes Amy to become deeply involved with the activities, and often she becomes interested in considering the content of the lesson, because of this deep commitment.

As we watched the videotape of the first activity of the light unit, "Beam Bouncing," Amy told me:

> At first a lot of kids didn't know really what they were supposed to do. Um, like it was hard drawing the diagrams. I had trouble where to put the mirror and everything. It was hard at first, then when I figured it out, it became easier. Mr. Ryan came over and helped me figure it out. Like first I had the mirror right here and here and here and he told me that if the beam hit the mirror right there, it reflected over here, so we tried it again and then this time we tried it like this, his way.

Amy points to the placement of the mirrors on the worksheet and shows me on the worksheet in relation to the light source.

Amy: Before he came, like on the diagram we were setting up the equipment, like it was easy, then, um I was looking at the diagram from the side and I didn't know how to put the mirrors in and everything. So when I asked him to help me I was able understand the rest and the rest became easy.

Ms. Shapiro: Oh, I see, it was at a different angle here.

Amy: Yeah. That was it. It seems like I was looking at it from a different angle, the wrong angle. This one here was hard because I didn't understand it at first. Then all at once it became easy once I understood the first ones.

Ms. Shapiro: I wonder...how do you think that you were able to finally understand it?

Amy: Oh, well, see, I didn't know how to do it at first. But once I figured it out, when Mr. Ryan showed me what we were supposed to do, and some ways of looking at it, then I could do it.

Amy, like Martin, values grasping the procedural aspects of science learning, and in fact Amy and Martin often have valuable exchanges of information concerning, in Martin's words, "what we're supposed to do on the worksheet." Where Martin's valuing of the procedures appears to be in terms of the enjoyment of doing the activity itself, Amy is interested in the accomplishment of and successful completion of the tasks. Her greater concern is in achieving the correct answers to the problems on the worksheets. Martin and Amy have established a collaborative relationship in which they help one another to understand what is the task of the lesson.

Amy is very resourceful in her endeavor to figure out "how to do the worksheet." During the lesson, "Bend that Beam," for example, we watched as she would disappear from the video screen for periods of time. She spoke about her absences:

Amy: Here I was going over to Carly's group, and um, to get some more ideas.
Ms. Shapiro: Oh, what are you getting?
Amy: Well, I wanted to know how Carley and Donnie and Mark were doing it. These guys (her own group) are just goofing around. They haven't done anything yet.
Ms. Shapiro: It seems that you're always the one to be helping the others figure out what they are doing.
Amy: Oh, well, I just like to be getting my work done and um, I like to finish my work. These guys [members of her group] are just goofing around and when we get to the end of the period, they'll just copy mine.
Ms. Shapiro: You don't mind?
Amy: Well I do. It sort of makes me mad. I get it done... and well, Melody, she just takes my book and copies it.

After the videotape I asked Amy if she could summarize briefly the main idea of the lesson. She responded:

> Well, it was to learn. Learning about light was the main idea.

In contrast, Donnie had responded to this question with specific ideas about the topic light, attempting an articulation of some of the main ideas of the lesson and the potential for application of the ideas:

> We learned that so, um you can see if something is in your way, and you need to get light onto something, then you can use mirrors and there's um, different ways more than one way you can get light onto a spot.

Theme II. Self Characterization: You have to be responsible. Like you have to work hard at your work and find the best way to do it. There are some very fun ways to learn. Some of the activities are interesting and I like to work with the other kids.

Researcher Image/Impression: An interest in the ways of learning science.

Ways of Learning Science

More than any of the other children in the study group, Amy spoke spontaneously with me about the *ways* that she learns in school. She spoke about the ways that she sees activities being presented by Mr. Ryan and about the ways that tasks are best accomplished in school. Amy appears to be more aware of the ways that tasks are accomplished in school and less aware of the actual content of the learning. Amy is very interested in performing well in school generally. She appears to be very concerned with being seen to do well. On several occasions when Mr. Ryan came over to Amy's group to ask other members return to their tasks, Amy made a noticeable effort to show him that she had been working all along, even though the others were not. The dominant theme which emerges for Amy, in this case study report is an interest and great resourcefulness in directing her attention to finding out what she must do to accomplish the tasks set before her.

Amy also defines science as "an activity that is fun to learn." She makes a distinction both in her personal constructs and in conversation between "working hard to learn" and "working in a fun way to learn." She makes the distinction between activities in which one is "doing something boring" and "doing something fun."

Another way that Amy's orientation to school learning in general was revealed was through observing and talking with Amy during her work in other subjects. During a language lesson, for example, students were asked to complete several verses by filling in blanks, using the subject of their choice. The verse given to the students to complete appeared as follows:

(Topic)
____

The important thing about _________ is ________.
________ is/are ___________, ___________ and
________. But the important thing about _______
is that you __________________.

Amy selected the topic, school. She wrote:

School

> The important thing about school is that you have work to do. School is full of kids. My school has about 400 kids. We do a lot of work in grade 5. But so far we don't do that much. But the important thing about school is that you have to work.

Mr. Ryan describes Amy in terms of her "excellent organizational skills," and as "one of the top achievers in the class. In Mr. Ryan's opinion, Amy is "a very together lady. Very impressive." Several children told me that Amy is the person they go to most often for help when doing science worksheets. Martin told me, for example, "I ask Amy to get help figuring out what you're supposed to do." Melody commented, "I like to work with Amy because she usually helps me and we get it figured out." Amy is extremely successful in accomplishing the tasks of the science program. She is admired by her peers and is often approached by others who need help.

Amy's interest in the ways of learning is also reflected in this theme. She made some initial comments during our discussion about her thoughts and feelings about learning science.

In an elaboration of her thoughts about learning science, she shared with me:

Amy: Well, Science is all right. Like I like learning some of the stuff, but not, like all of it because sometimes it's quite boring. Other times it's very fun.

Ms. Shapiro: What is it that you find boring?

Amy: Well, some things I don't like. Well, like electricity and light are very fun, but some things, like last year we learned about sound. I didn't really like that because you had to really learn a lot of things in just a few weeks, and then you had a test (makes a face). You had to learn all about the eardrum. You have to watch films and do all sorts or things to learn. There was just too much to learn.

Ms. Shapiro: That made it boring.

Amy: Yeah, too many little things to remember all at once. [Amy's personal construct number 15]. I don't like that. It's more fun when you get to do things with it, like in electricity we made bulbs light? And in Science now we're making light go in different ways. It's more interesting because then you yourself get right into things.

Ms. Shapiro: Were you interested in knowing about the eardrum?

Amy: I guess so. It was sort of neat seeing it.

Ms. Shapiro: And how about light?

Amy: No. Not always really. It's not what I'd pick. But some of the things are really interesting that we get to do like the ways you can make light go.

Amy is concerned with the tasks of learning more than the content. She finds active participation enjoyable and valuable because it seems that for her is a more interesting way to accomplish the task set before her. She is interested in taking on her responsibility as a student, but as has been mentioned previously does not appear particularly interested in the subject matter content.

Amy also commented on other ways that she could be involved in the learning which she felt would make learning more fun. During the large group discussion of the first lesson, she pointed out,

> Here, listening to the other kids helped me to learn. It's easier to, um when um, I like to have other discussions like this one, that you can join in to. Listening to the other kids made ideas pop into my head so that I could give an answer.

Amy also says, in contrast to Martin and Pierre, that the comments which Mr. Ryan makes on her paper are helpful, particularly if a test is a part of the culmination of the study.

> I like to look over the comments. I find out that there, are, here, for example, there is some things that I didn't do right, like the next time, if you do this again, you'll probably know what to do. And if you have a test then you'll be able to answer the question.

Amy's second theme interelates with the first, in that she emphasizes ways of learning science and does this with a sense of resposibilty for understanding the procedures of learning as well as possible. Although Amy frequently comments on the beauty and intriguing qualities of light phenomena, this interest appears secondary to her interest in and emphasis upon the ways that learning takes place. During the review of the discussion on color, Amy reflected:

> Listening to what the other kids were saying here helped me to learn.

Her further interest in the ways of learning was revealed in her comments on the lesson, "So Deceiving," in which she commented:

> Working with the other kids and doing experiments is a fun way to learn. Doing things is a lot more fun way to learn than just listening.

Again, the way of learning science, or of coming to the correct answer was seen to be of greater interest to Amy than the actual content of the lessons in the discussion on Mark's revolutionary idea concerning the bent pencil phenomenon:

Amy: I forgot what Mark said on Tuesday, so I just wrote, um, what I thought before, that maybe it was the because the beaker is round, and maybe because of the water.
Ms. Shapiro: Oh, I see, one or the other?
Amy: Maybe both. I don't remember what Mark said. But I know that he was right. (laughs) He wasn't speaking up up too loudly. I couldn't hear. Mr. Ryan said the answer out loud. I got the right answer on sheet after that. He put it on the overhead.
Ms. Shapiro: Okay. Here's the question. (points to the worksheet) What did you put?
Amy: I don't remember what it was.
Ms. Shapiro: But did it make sense to you at the time?
Amy: It was such a long long paragraph answer. I like, just forgot what it was. I just forgot it, I guess.
Ms. Shapiro: So you probably don't recall whether that made sense at the time.
Amy: No. Mr. R said, cause he said that , I remember a little bit - that because Dean took what, um last week's problem, you know the worksheet we did, and he then combined that with what he learned there with this week's problem, that's how I think he did it. He sort of combined them together and that's how he came up with the right answer.
Ms. Shapiro: Can you tell me why the pencil appears bent in the water?
Amy: No! (laughs)
Ms. Shapiro: Do you think that it is important to know?
Amy: Well yes. Like if we have test on it, then yes, we have to know it and study it and learn it.

Ms. Shapiro: And if there is no test, do you think that it is important or valuable to know these things about light?

Amy: No. I don't think so. They're sort of fun, but I don't think that it is something I am going to use ever.

Amy recalls clearly how Mark came to the correct answer, but not what the answer was nor could she relate any of the thought or ideas relevant to the development of the concept. It is clear that her dominant interest is in the ways of learning and achieving the correct answer, this orientation has guided her to notice how the understanding was achieved in Mark's case, rather than focussing on the mystery of the content of the lesson, as Donnie had. Though she does not see any reason for knowing about light, she does take the responsibility for learning very seriously.

The Interaction of Ideas About the Nature of Light and the Classroom Presentation of Information

During the review of the videotapes of lessons, Amy did not comment as often or as readily as the other students in the group about the concepts which were presented in class which were in conflict with her own. It seemed that she actually considered the ideas about light only when I suggested that she consider them. But more than the others, I noticed that she found reflecting on videotapes to be a very intriguing experience. She would often ask to review a segment.

she was actually considering many of the content ideas for the first time. When I asked Amy to consider her ideas about the actual content of the lessons, it seemed at first, difficult for her. She had not spontaneously discussed any of her insights and confusions about content with me. As we reviewed the content of the lesson, Amy showed that she was very adept at reflecting on her own thinking about as she worked in Science. These instances showed her interest in and ability to become aware of and articulate her thoughts about content information during the classroom presentation, although she had not previously shown an interest in the specific content information. In an early example, we discussed the difficult acceptance of the idea of the reflection of invisible light rays off all objects.

> Mr. Ryan: So, I guess we've decided that light travels from the thing we see to our eyes. And we see it. Does anyone not agree with that?

Ms. Shapiro: Did you agree with Mr. Ryan?
Amy: Well... I'm not sure. Yes, I think so. I agreed a little bit with some of the things about light. I wasn't sure about the um, that answer, that the answer was right.
Ms. Shapiro: His answer?
Amy: Yeah.
Ms. Shapiro: Nobody raised their hands there. But I noticed that some kids had puzzled looks on their faces.
Amy: I saw the other kids, um I disagreed a little too. Because I wasn't sure that the answer was right. I thought that um, like light is something else, not the thing we see.
Ms. Shapiro: What do you mean?
Amy: Well, I think he was saying that the light and

the thing, um the light from the thing is what
we see, or something like that?

Amy and I replayed that portion of the videotape and she became stronger in her disagreement with the ideas presented:

Mr. Ryan: And so the reason that I see Martin
is because the light reflects from Martin
into my eye.

Amy: I don't agree with that at all. Only some things have lights. Like the t.v. set. Like you don't really need lights to see the t.v. set. Unless it's very bright. Like on this videorecorder, you can see the little light here when it's on. And some kinds of toys. You can see these. And some stickers that glow in the dark. You can see those too.

Amy also remarked that when some of the other students commented on the question of light pathways, that that this had helped her to understand what was meant, and that it also confused her about what was meant:

Amy: Some people said that it [light] went in straight lines, some people said that it went in circles. That made it clearer to me. But, I think that I really thought that he meant something else.

Ms. Shapiro: Oh? How do you mean?

Amy: Well, (laughs) I'm not sure! Maybe if I looked at it again.

We reviewed the videotape again and Amy was able to articulate her confusion:

> Mr. Ryan: Do you have any idea as to what kind of path or pathway light would travel? For example, when you go home, you take a direction, you have a direction, you take a pathway home.

Amy: Here he said um, 'when you go home, you take a pathway or directions, but like, um he said pathway, but I didn't get that because the thing is I'm not light! So I don't really see what he means.

Later on, Amy revealed another confusion concerning other aspects of the discussion about light pathways which she had not mentioned in class, nor the first time through our viewing of the videotape:

> Mr. Ryan: How does light get from there to there? Does it go in circles? Does it travel in zig-zags?
> Charles: It goes through wires?
> Mr Ryan: Well, there are lots of lights that get there without flowing through wires. Does it go through wires? There are no wires from the sun.

Amy: I couldn't figure out here if he meant how does it get to go there. But then I got the idea that it goes in a path. At first I thought that Mr. Ryan said it went in wires or tubes or things like that but then when someone said it goes straight, straight, then I got the idea that it wasn't what I thought. I thought, um, like I wasn't sure if he was asking how can you get it to go a certain way or what makes it do that? Then someone here said, um it was Chan, um it goes in circles and I said, 'that can't be true' in my mind, 'that can't be the right answer.'

Although Amy did not often speak of her way of thinking about the content, when I probed her thought, encouraging her to think about content, she showed an interest in thinking about the ideas. Though her dominant orientation is to tasks and their accomplishment, in this example to figuring out just *what* was being asked for in the question, she shows that reflecting on ideas about the science content is well within her range of ability. Some of the activities and experiences become "sort of interesting" to her as she pursues them. In this way, Amy's orientations to learning about science 'trips' her into discovery of an interest in understanding the nature of light. The predominating guide of Amy's though and action during the light unit is her interest in task and in the ways of learning. Yet, these interests may guide her into new and fascinating insights, and perhaps even an interest in the topic, light.

6.11 Case Report VI: PIERRE

6.11.1. Some Initial Observations and Impressions

Pierre approached me on my first day with the class. When Mr. Ryan introduced me to the students, I explained what I hoped to accomplish in the classroom and asked the children to consider the extent to which they would like to become involved in the study. Pierre came over to speak to me as I stood by the side of the room.

Pierre: Are you going to be here for the science fair, Miss?
Ms. Shapiro: Yes, I'll be here through the end of June. It's coming up soon, is it?
Pierre: Yeah, in April, I think. I did dinosaurs last year and I've got all the models on my desk. Do you want to come up and see?

Pierre's desk was situated in the loft area in the classroom. He had set up a small display of model dinosaurs on the front edge of his desk. He explained that he had used the models in last year's science fair project. He told me the name of each dinosaur and described the environment and habits of each one in detail. Pierre spoke quickly and enthusiastically, sharing his collection with obvious delight.

> Pretty neat, huh? I had these in the science fair project last year and now I'm building a model world for them at home. For the science fair, I, um, read a lot of books about dinosaurs and people asked me questions and stuff. This year I'm going

> to do models of outer space and rockets and read up on the planets and all of the space flights and maybe make a model rocket.

Pierre rustled through his desk and pulled out several paperbacks on various science topics. He read the titles as he showed me each book, "_Dinosaurs_, _Forces that Shaped The Earth_, _Rockets and Jets_, and _Space Travel Today_."

His Science notebook, a three holed folder, held the xeroxed worksheets from his most recent Science unit, "Batteries and Bulbs." The cover had obviously been spontaneously decorated over the course of the term (Figure 6-15). I asked Pierre to tell me about his drawings on the cover of his notebook.

Pierre: Oh, this is a scientist's _lab_ratory. It's got all the stuff he has that he's working on, and there's his coat and there's his cat that lives there. And that's his picture there.
Ms. Shapiro: It looks like a very active, exciting place. Have you ever been in a science laboratory?
Pierre: No, I never been in one.
Ms. Shapiro: How do you know then what to put into the lab?
Pierre: In books and things and movies there's pictures that, so, um, gives you an idea about what they look like.

Though open and outgoing in personal conversation, I noticed that Pierre was one of the quieter members of the class. He seemed serious about his work, and sought the help of other students often. However, I did not observe him asking Mr. Ryan for help at any time. Pierre was usually working alone. He observed others more often than he participated with them. Pierre rarely contributed spontaneously during small group discussions when I brought all members of the study group together. He also seemed to have some difficulty reflecting on his experience of learning.

During our first private conversation, I reviewed the purposes of my project and my interest in talking with him. Pierre surprised me by asking if I were a speech therapist. He told me that he had worked with a speech therapist in the first grade, and that his brother, now in the fourth grade, had weekly sessions with a speech therapist. He wondered if we would be doing the same sort of work. Pierre told me that his parents had asked that he be kept from progressing after his first year of pre-school. I then read the contents of Pierre's pupil progress folder and learned that his parents had been concerned that he was not maturing physically, nor in the acquisition of verbal skills. Mr. Ryan considered Pierre to be an average, capable student. He was not aware of Pierre's early school history. Pierre was physically smaller than the other children his age, but he displayed unusual athletic skill on the playground. He told me that Physical Education, Art and Science were his favorite subjects.

6.11.2 Part I: Thoughts and Feelings About Learning School Science

In all of our conversations, Pierre exuded delight in science study and showed a great interest in learning science. Therefore, it was surprising that he had checked only the second highest positive response on the survey checklist, in reference to his feeling about science learning, "I like it," instead of what I had expected, "I really like it." Since he had shown so much enthusiasm in the description of his science activities, I pointed to the less than top overall rating he had given Science, and asked him to help me to understand.

Ms. Shapiro: You really seem to like Science, but you didn't give the highest rating here. Can you tell me a bit more? How do you feel about learning science?"

Pierre: Oh, it feels just great! I just love it. You get to learn all kinds of interesting things about the earth and about dinosaurs and about the human body, and you get to do experiments and things... I don't really like learning about light, though.

Since at this point the class had not yet begun the study of light, I asked Pierre how he had come to make this decision. I asked him if he could tell me what it was about the topic light that he did not like:

> Well, there were these little batteries and bulbs and holders and stuff and wires. You had to light the bulbs and all. You had to get it to light and I just couldn't do it! I tried and tried and I just couldn't get it to work. It was just too hard. And then you had to get all the different ways. It was just too hard. It was sort of interesting in some ways, but it's sort of hard, you know?

Like Donnie, Pierre had equated the study of the topic, light, with the unit previously and most recently studied, "Batteries and Bulbs," especially since, as he remarked, "we made light before," and Mr. Ryan had told them that they would be studying the topic, "Light," next in Science.

Pierre's Ideas About Ways of Learning Science

Pierre's classification of Typical Science Activities grouped by preference appear as follows:

"A+" (Pierre's designation)

Do science fair projects

A "The activities which you like the very best"

Watch demonstrations by my teacher
Write reports on science topics
Do experiments on my own
Do experiments with other kids
Read library books on science topics
Talk about science ideas with other people
Go on field trips
Make science diagrams and drawings

B "The activities which you think are just "ok"

Read the textbook

C "The activities that you don't like"

Do science worksheets

Pierre created and gave an "A+" to the activity "Do science fair projects. When I showed him his groupings, he looked at them silently, then laughed and said,

> Yeah. Mmmmhmm. I sure do not like the worksheets all right. Yuck. See? I like almost everything else though.

Overall, Pierre's regard for science must be described as enthusiastically positive. His interest in pursuing science outside of the classroom was clearly greater than for any of the other children in the study group. He wrote on his survey form that outside of school "I like drawing things like models and dinosaurs and I like making things." Pierre's spontaneous drawings on his Science notebook covers portrays the richness of activity and endeavor with which he regards the environment of the science laboratory (Figure 6-15).

Despite his expressed enjoyment of Science generally, Pierre says the science learning is "fairly easy" and often comments on the difficulty which he has in understanding some of the ideas which are presented. Peter says that "the science you learn in school is different from the science outside of school, because, it's different because at other places you learn different things."

6.11.3 Part II: Summary of Pierre's Ideas and Feelings About Light and the Study of Light Prior to Undertaking the Unit

Introduction

Pierre's views about the nature of light, prior to the study of the topic, are presented in a summary form below.

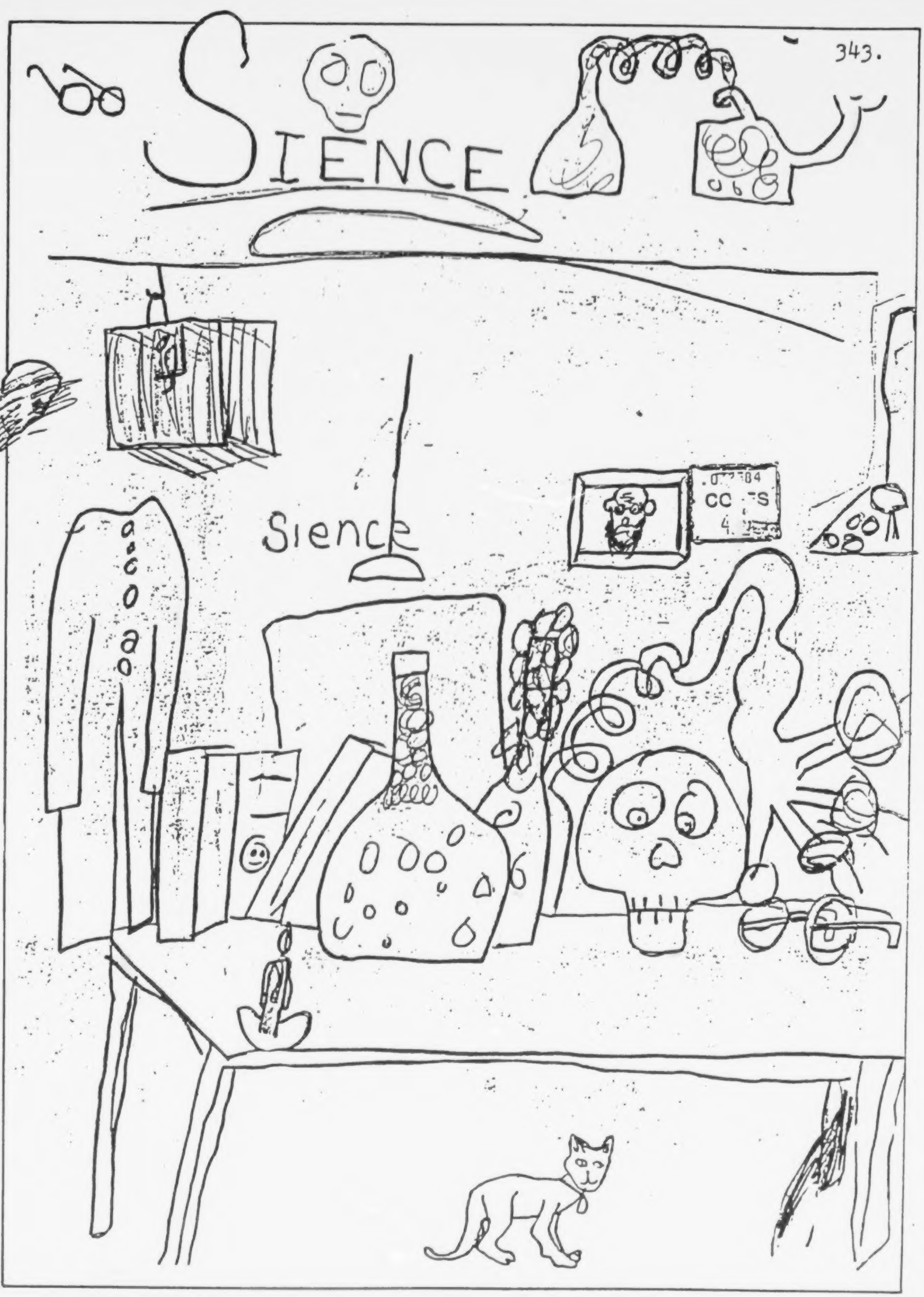

SIENCE
Sience

Figure 6-15. Pierre's Science Notebook Cover

What is Light?

> Light is rays, like rays of light. Like, there's light from the sun and from lightbulbs and flashlights and lasers mostly. And lasers are magnified sunlight.

Comment: Pierre speaks of light in terms of visible and evident rays. He shows an awareness of at least one aspect of the basic principle governing the creation of laser light.

Where is the Light in This Room?

> The light is in the flourescent lights up there and that makes it bright in the room, well in some places in the room, anyway. There's no light right now because it's bright outside.

Comment: Pierre suggests that there is no light in the room when the light bulbs are not on.

Association of Light Phenomena With Everyday Objects

Pierre's association of light phenomena with everyday objects is shown and contrasted with the class as a whole in Table 6-17.

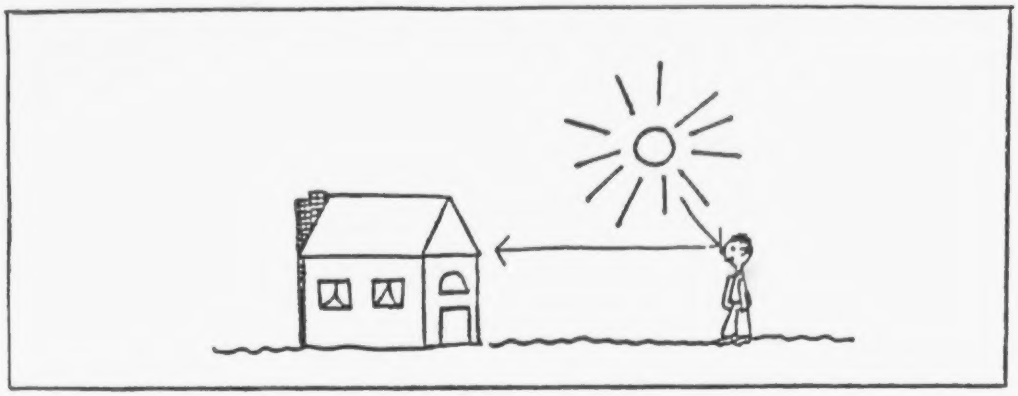
Comment: Most of the children who checked light in association with "eyes" stated that light is required so that we may see with our eyes. I mentioned this to Pierre who stated that we see in the dark, so light is not important for vision.

Table 6-17.

PIERRE'S ASSOCIATION OF LIGHT WITH EVERYDAY OBJECTS

1.	ELECTRICITY	28	+
2.	CAMERA	28	+
3.	TELEVISION	27	0
4.	LASER	27	+
5.	EYES	25	0
6.	RAINBOW	24	0
7.	MIRROR	23	0
8.	STARS	21	+
9.	X-RAY MACHINE	19	+
10.	MOVIES	19	0
11.	FIREFLIES	19	+
12.	PLANTS	12	0
13.	MICROSCOPE	6	+
14.	TELESCOPE	6	+
15.	ROCKS	3	0
16.	BIRDS	2	0
17.	MAGNIFYING GLASS	2	0
18.	PENCIL	1	0
19.	CANDY	1	0
20.	CLOTHING	1	0

How Does Light Allow Us to See Objects?



The light shines into the eyes of the boy. When the light shines into his eyes, that lets him see the house.

Figure 6-16. How Does Light Allow Us To See Objects? Pierre's Response

Comment: Pierre's view is that light is required in order for the eye to perform it's task of "seeing" the house. This is in part, but not wholly the scientist's view of how objects are seen, and could be an excellent starting point for the development of this idea.

What Happens When Visible Beams of Light Travel to An Object?

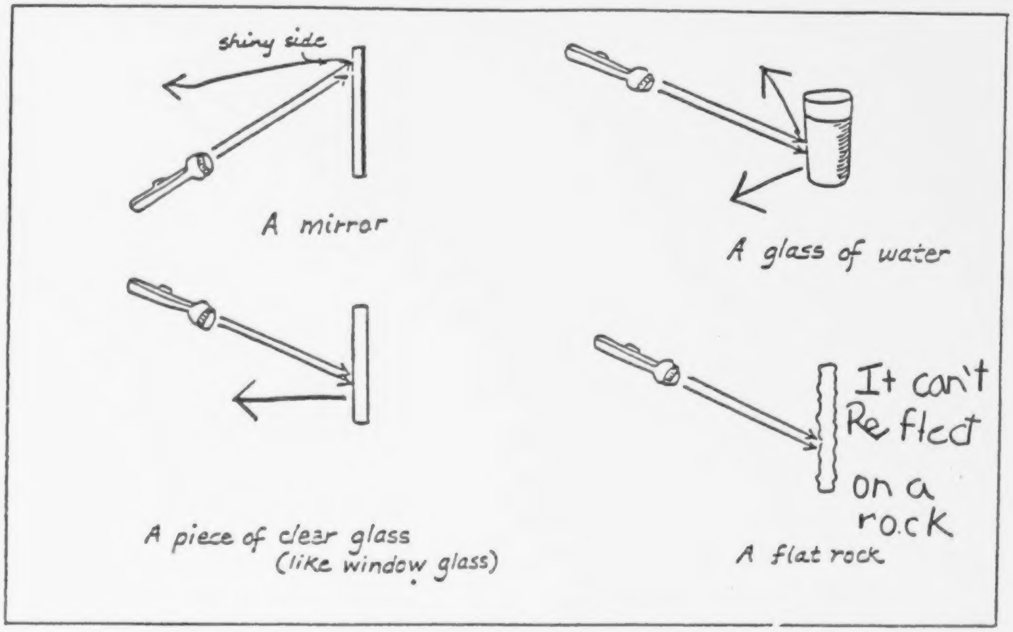

shiny side
A mirror
A glass of water
A piece of clear glass (like window glass)
It can't Reflect on a rock
A flat rock

Figure 6-17. What Happens When Visible Beams of Light Travel to an Object?

Comment: Pierre's drawings show light reflecting off every object except the rock. When I asked him about this, he commented that even though he had not drawn arrows in, that light beams would have to go through the piece of window glass and the glass of water and that only a little bit would actually reflect off each of these objects.

How Do We See Color?

> I see, like a blue pencil? (pause...audible sigh...Pierre drops his eyes to the desk...pause 4-5 seconds) That's a tough one. I don't know....,um,

> with my eyes and my brain I guess. If it's blue, my eyes see the blue and my brain tells me. I don't know how, though.

Comment: Pierre's view is based upon his present understanding of vision. He is aware that he does not completely understand the mechanism of vision.

Pierre's Feelings About Light and the Study of the Topic, Light

> I like light. Sometimes not. At night I get under the covers and shine it through and on my face and hands and my brother gets real scared. Like that. (Shows me how he shines the flashlight) Oooh, when it's really dark it's really cool. You can see the blood in your hand.
>
> We studied it last year and we opened a light bulb and it was really cool inside. This year we've done electricity with making light with batteries and wires. That was fun.

Comment: Pierre recalls participating in quite a bit of play with light which he relates with obvious pleasure. He relates the study of batteries and bulbs to the study of light. Several children have commented on how interesting it was to observe the inside of a light bulb in a classroom in the past.

Part III: Pierre's Personal Orientation to Science Learning: Revisiting the Study With Personal Constructs and Emerging Themes -- Paradigmatic Instances of Thought and Action

Pierre's Personal Constructs

Pierre's personal constructs relating to his experiences while learning about the topic, light, are presented in Table 6-18. His comments on the factor groupings of the constructs are shown in Table 6-19. The themes of Pierre's personal orientation to science learning are presented below.

Theme I: Self Characterization: Science is learning about all kinds of interesting thing. It's about the dinosaurs and about the earth and the human body, and you find out how things work and the way that the world used to be.

Researcher Image/Impression: Interest in the story of science. Fascination and delight with the specific facts and details of knowledge of phenomena. A natural historian.

The Story of Science

Pierre spoke of the enjoyment of hearing the "story" of science in class, as did several of the other children in the classroom. Interest was particularly evident during a session in which the children listened to the school nurse and their classroom teacher describe human growth and sexual development. A question and answer session followed. Melody had told me how interesting she found the questions which other students had during these periods. Amy commented that listening to lecture and question and answer periods helped her to "picture new ideas in my own mind. Somebody else's idea gets you to thinking in a new way sometimes."

I did not observe Pierre asking questions during these periods, but he commented on how interesting he found listening during this time to for example, a detailed description of the environment of Saturn, an explanation of how a video recorder works, or the answers to specific questions which members of the class pose. Pierre speaks of "the Science lecture part," of the lesson, referring to the shared large group discussion, when Mr. Ryan answers student questions or he gives the children specific information on the nature of phenomena. Pierre contrasts this with the pre-activity discussion, which he calls "the boring part of the lecture," the pre-activity sessions in which "he's just telling you what you're supposed to do, and you just want to get to do it so bad" (Construct 8). In the former instance, Pierre says that "Mr. Ryan is giving us all kinds of really interesting information." His delight in this process reveals an orientation to science learning as an ongoing discovery of the way the world truly is. This appears to be a very enjoyable part of the direct experience of science learning for Pierre, and supports his orientation to learning science as a body of knowledge which is accumulated over one's school career. Pierre comments, for example, on a segment of the lesson in which Mr. Ryan is discussing material which Pierre recalls having studied previously.

Table 6-18.

PIERRE'S PERSONAL CONSTRUCTS

1. Experimenting.	524511121554454525134525454512155 3353	1. Mr. Don is just telling us things.
2. Just really enjoying the activity.	444522122344354445523355445552155 54135	2. Correcting and copying down things
3. You know exactly what to do.	133332222424454433233215445323255 5251	3. You don't know what to do at all.
4. Helping someone else to answer.	233333322424144523513311145222134 5111	4. Not giving away any of the answers.
5. Confusing to everyone.	544534444453413555235455124545421 1325	5. He (Mr. Don) explains to us. He tells us what it means.
6. Group activity. You read questions and ask them to each other.	241223243323423423511351333221232 3425	6. You do it all on your own.
7. Having trouble and have to ask the teacher for help.	241234344224322143523251122133311 1512	7. Don't need any help at all.
8. You want to get going and do the work just so bad.	432443234543444424233315555521255 5254	8. You're having trouble and no one will help.
9. You're thinking up on your own what you want to do.	535524444543344555153525455532555 5255	9. The teacher is telling you what to do.
10. You're really worried about getting it right.	334234344333323222523344122354344 2135	10. Not worried about getting it right or wrong, just enjoying the experimenting.
11. You really want to do it. You're working hard thinking of something.	253444454433335333133324353432345 5241	11. Not doing anything at all. Goofing around.
12. Doing stuff you have to do.	253444454324433311443114221253523 3533	12. Doing things you really enjoy doing.
13. You don't understand the question.	445545444345413535344355435333552 2214	13. You're finding out from other kids what to do.
14. You're getting all your worksheet done.	534423443445454423353325155433255 5351	14. You're stuck.
15. You're learning lots of interesting things.	233213223343355222332114353311245 5142	15. You're sort of bored.

Table 6-19.

PIERRE'S STATEMENT GROUPS

Group 1:
You know exactly what to do.
Helpin someone else to answer.
Mr. Ryan explains it to us. He tells us what it means.
Don't need any help at all.
You want to get going and do the work so bad.
You really want to do it. You're working hard thinking of something.
You're finding out from other kids what to do.
You're getting all of your worksheet done.
You're learning lots of really interesting things.

Pierre's Statement: I know exactly what to do, or I'm finding out exactly what to do. I'm really liking doing it and I'm really learning a lot of interesting things.

Group 2:
Experimenting.
Just really enjoying the activity.
Don't need any help at all.
You're thinking up on your own what to do.
Doing things you really enjoy.

Pierre's Statement: I'm experiementing and thinking up things all on my own to do.

Group 3:
Confusing to everyone.
You're really worried about getting it right.
You don't understand the question.

Pierre's Statment: I'm really worried when I just don't get the question that I won't get it right.

Group 4:
Helping someone else to answer.
Group activity. You read the questions and ask them to each other.

Pierre's Statement: This is working with other kids where you're getting help and giving help sometimes.

in which Mr. Ryan is discussing material which Pierre recalls having studied previously:

> I learned this part about the eye last year. In grade four we studied about how the eye works and which way it moves and everything. That was at my other school. Right here, this is where Mr. Ryan is going to talk about the picture in the eye being turned upside down. We learned that part last year.

In this segment, Pierre's comments support the view of a consideration of science learning to consist of pieces of information or "parts" which are covered in different grade levels. I asked Pierre about the purposes of learning science in the elementary school.

Ms. Shapiro: Do you think that it is important to study science in elementary school?
Pierre: Yeah, um, I do. You might want to continue studying in high school and at the university. In junior high school it gets harder so you have to get ready for that. Also, because you might want to become a science teacher or a scientist or something.
Ms. Shapiro: Do you feel that studying science helps you in your life at all?
Pierre: Well, yeah. It's sort of interesting like, light, um light, like light is important to know about because we use it all the time and we need to know how to fix light bulbs and things.
Ms. Shapiro: How about the lesson today, for example, can you tell me what we learned today?
Pierre: Well, sure, it was the light, like, which way light can go, like it went this way and then it went that way.
Ms. Shapiro: Is this valuable or important to know this?
Pierre: Well, it's interesting. It's fun to do when it's not too hard to understand what you're supposed to do.

Even though Pierre comments that science study is important for continued success in school, there is much evidence over the term that he values science learning in the study of science for its own sake. The conflict for him is evident in his concern that he has some difficulty with science concepts, and that he often does not feel that he is performing well in the school science program.

Though Pierre delights in the study of science, it became apparent through our ongoing conversations that he did not value the classroom study of science as greatly as he did learning science through science fair projects and the projects of his own design. Of the six children with whom I worked, I found that Pierre pursued science learning more consistently both inside and outside of the classroom. Yet, for Pierre, the school science learning experience was often a source of difficulty, conflict to some extent, which led to anxiety.

Recent thinking in science education has been concerned with an over-emphasis by many science teachers on an approach which views the child as a "receptacle of information," and which views the teacher as "transmitter" or "pourer of information" into the child. Yet, there are important aspects of the experience of sharing the 'story' which some individuals are wide awake to or find interesting. Pierre's personal orientation to science learning is clearly linked to his view of science as a set of facts concerning the nature of phenomena. We watched the videotapes as Pierre wrote down terms or phrases pertaining to Mr. Ryan's lectures:

Ms. Shapiro: What are you doing here?
Pierre: There I was writing down those words, you know that tell about the light and which way it goes when you put it through the beaker of water?
Ms. Shapiro: Were you writing on a worksheet here?
Pierre: No. I just wrote them down so I could remember what they were here. I just like to keep ahold of them so I can remember them.
Ms. Shapiro: What were the words that you wrote down?
Pierre: AAaauuumm. Convergence and divra- or something.
Ms. Shapiro: Do you recall what they mean?
Pierre: Yeah. Convergence is when they come together and cross. Divra--um--gence is when um, oh, (laughs). It's sort of hard to remember. That's why I wanted to write it down (laughs).

Pierre's natural interest in making notes and in keeping records was apparent throughout the Light unit as he made notes on small pieces of paper which were stuffed in various places, in his Science notebook, in his desk, or in his pencil box. Frequently, he wrote down terms on the back of the worksheets in his Science notebook.

Pierre's parents separated during the term, and he moved to another school district for several of the last months of the school year. I visited Pierre in his new apartment, where he showed me the science corner of the room which he shared with his brother. His boxes were filled with drawings and notes on the subjects of his study--dinosaurs, the earth, rockets and light.

The Pleasure of Sharing the Story

Each day after lunch period, Mr. Ryan read the class part of an ongoing fiction story. During this time, the children were allowed to draw or write, and as I was particularly interested in the choices which they had made during their free time periods, I sat with them and watched closely. Pierre consistently brought out his paperbacks and project books on science topics. Throughout the period I was in the classroom, I saw that he had books on outer space, robots, the solar system, volcanoes, the formation of the earth, and numerous books on dinosaurs.

Pierre noticed my ongoing interest in his books, and always made a special effort to show me what he was reading or doing during the story time. One day, he had a library book at his desk which he said he had picked out for me. It was entitled, Science Experiments With Light. He flipped through to some activities which he said that he thought would help in my project, and described in detail those which he had tried at home. He told me that I could keep the book until its due date if I liked. As he described each activity in detail, it became clearer to me how greatly Pierre valued sharing his knowledge and understanding with me. He was clearly fascinated with the story of science itself, but there was an aspect of sharing findings with other people, which was particularly evident and valued by Pierre, in the experience of the science fair, the way that he had invited me to his desk at the beginning of the term, and the enjoyment which he expressed for Mr. Ryan question and answer periods or when Mr. Ryan was giving science content information.

Despite continued evidence of his enormous enthusiasm for science and for the sharing of science knowledge, Pierre expresses an ongoing anxiety in the school Science program.

Theme II: Self-Characterization: Sometimes you just don't get the idea, you know. Well, science is ah, a little more difficult than any other thing because you gotta look at it, test it, and try it, and stuff like that, but in math you just have to look at the question and then you have to do it. Sometimes I get really worried about getting the things right in science.

Researcher Image/Impression: Anxiety. When Pierre does not understand what he is to do, or when he does not believe what Mr. Ryan is telling the class, learning science in school becomes troubling.

Anxiety

As with Pierre's recall of the story of the workings of the eye, this "story" of science is viewed as another "bit" or "part" which is added to the total picture. As Pierre commented, "you get to learn all kinds of interesting things," 'things' that he is interested in knowing about. Being told the story is perhaps, the nearest thing to direct personal experience of the content, particularly when the question answered is one that you want to ask. The experience of hearing the story is itself a direct experience. Verification of information gained in such a manner is in terms of personal experience, for there is little discussion about the tentative nature of findings, or of the variety of explanations which have been put forth by different thinkers to explain events. For Pierre, the information which Mr. Ryan presents is either right, or if he cannot verify it, that is, make the discovery for himself, then the information which Mr. Ryan presented must be wrong. Pierre takes a strong stance on this position, for example, during the conversation about the discussion in which Mr. Ryan tells the class that the reason that objects are visible is because light reflecting off of the objects shines into the eyes of the observer.

. . .

Pierre: Yeah, he said that, but I didn't believe it!
Ms. Shapiro: You didn't believe it. Do you think he was right?
Pierre: No! He was wrong! That's silly.
Ms. Shapiro: So, how is it that you see me?
Pierre: It's the light. It makes me and you and him see everything. All the people in the class. Without light shining on things, you wouldn't see anything.
Ms. Shapiro: I see, then just like here on your diagram--
Pierre: The light shines into his eyes from the sun and it lets him see things there.
Ms. Shapiro: So, when Mr. Ryan asked if people thought differently than he was saying, why didn't anyone put their hand up?
Pierre: Well, I didn't because, um, well, the teacher said it was that one way, and I didn't want to say it wasn't the way that he said, so...

Pierre had interpreted Mr. Ryan's comment on the fact that "People used to think that the reason that we see things is because there was something coming from our eyes to the object," coupled with the question, "How many people think that that's how we see?" to suggest that one would be wrong to believe such an idea. Pierre felt very reluctant to contradict the teacher even though on a number of occasions, he showed that he did stated that he did not believe what Mr. Ryan was saying. Throughout the unit I also noted that Pierre also expressed expressed considerable concern and anxiety about getting the right answers on the worksheet. [Construct 10 and comments on statement group three]. His reaction to the teacher's comments on his worksheet was quite negative. In this way it was similar to Martin's.

Ms. Shapiro: What did you think of this comment Mr. Ryan put in your book about the points where the beams cross?

Pierre: Oh. I read that. Sometimes I go, 'all right,' and sometimes I go 'aw, bblbbkdfgfjdflkd (sic). Sometimes they're not too helpful. I don't like them sometimes.

Ms. Shapiro: What sort of comments do you find helpful?

Pierre: Oh...comments? Well, if he just wrote a comment, um, but he says that this is right or not right and stuff.

Ms. Shapiro: These statements that he writes, here for instance. What do you call those?

Pierre: I'd just call them comments, I guess. I call them nothings sometimes. Sometimes he tell us to correct it and he shows it to you, you know, and that's sort of helpful. But I don't like doing the corrections. I just hate it.

Like Martin, Pierre finds corrections on the worksheet to be exasperating, and it appears, through observing his reactions to the activities, that he finds the experience of being corrected to interfere with the enjoyment of science in the classroom. Once Mr. Ryan makes the comments or corrections, there is no requirement that the students follow up by making corrections, nor does Mr. Ryan discuss the common errors made by students in class. Each child knows that the corrections must be made before turning the worksheets in. Mr. Ryan always presented the correct answers on the overhead projector during the large group discussion following the activity period. Therefore, errors reflected not only lack of understanding of the correct answers, but if they were not placed on the worksheet, there was simply a lack of interest in copying down the correct answers. In Pierre's case, lack of understanding led to a frustration with the entire process, and seemed to destroy part of the enjoyment of his total experience of learning science. His frustration and subsequent lack of faith in some of Mr. Ryan's ideas also interfered with his taking the responsibility to reconsider some of his own ideas. His comment that he "just did not believe" what Mr. Ryan was saying, was perhaps, used to justify not listening further to the ideas which Mr. Ryan presented, and showed that he simply chose to continue to believe his own ideas rather than remain confused. In Group 2 of Pierre's construct groupings, shown in Table 6-20, we see portrayed an intense desire to become deeply involved in doing the activity contrasted with frustration in not being able to move forward in his usual approach to pursuing a topic.

Table 6-20.

PIERRE'S CLUSTER #2 and OPPOSITE POLES

*1. Experimenting	1. Mr. Ryan is just telling us things.
*2. Just really enjoying the activity.	2. Correcting and copying things down.
7. Having trouble and have to ask the teacher for help.	*7. Don't need any help at all.
*9. You're thinking up on your own what to do.	9. The teacher is telling you what to do.
10. Doing stuff you have to do.	*10. Doing things you really enjoy doing.

*Constructs In Cluster #2

Pierre's feeling of being restricted is portrayed in Theme II and appears to affect what he has been attentive to, interested in, and wide awake to in the presentation of concepts in the light unit. In contrast, Pierre's real enjoyment of involvement of science learning is seen in the snapshot portrayal of Theme III.

Theme III: Self Characterization: Learning science is learning about all kinds of interesting things (Construct 15). At home I have a special science place in my room where I do science projects and try out all kinds of things. I find out a lots of things on my own sometimes.

Researcher Image/Impression: The enjoyment of working and discovering on his own.

Pierre talked with me about his experiences in trying one of the activities from the light unit at home. He had built his own light source and described his experiences with showing his younger cousin how it worked and what he was doing with it in school. He told me that he also made models at home and had a special science area in his room where he had tried the activities which were done in class. Mr. Ryan was not aware that Pierre worked this way on science at home, and commented that Pierre had never told him about his home science experiments, nor had he referred to them in class in the way that Martin had.

Spontaneous Discoveries

Pierre and I watched several examples recorded on videotape of spontaneous situations in which he had been working alone during a quiet activity portion of a lesson and had made a special discovery during a 'messing about' time, or what Pierre called, an "experimenting time," a time when "you're doing it all on your own." [Construct 6] In one such incident, Pierre was playing with shadows against the light:

Pierre: I was trying to figure out how to turn the light over here and we were trying to plug it in. The light kept going on over there, so, every time I saw it, I put my hand close to the thing and I was going, ooooooh. (Laughs) And I see my shadow over there and I was showing how, well, I really don't know how I don't really understand how every time your hand goes close to the light, it makes a big shadow.
Ms. Shapiro: And so you--
Pierre: (Excited) And every time you go really forward, it, it makes a little small shadow! Pretty weird isn't it? I tried that with my flashlight here, and I thought there, you... how do you do that? How does it do that? Wow!

Though Pierre's experience was not part of the worksheet tasks assigned, he was completely engrossed in the activity. It seemed to make an important impression on him, and upon his sense of self confidence in being able to make such a discovery by himself. Later in the unit on March 19, Pierre again used these basic impressions and observations in an attempt to provide an explanation for the bent pencil phenomenon which had puzzled so many children in the class.

This was an exciting segment to observe for several reasons. First, Pierre knew that his answer was not counted as correct by Mr. Ryan, yet, he was still able to pursue his own line of thought and reasoning to give his explanation of the phenomenaon based upon his own understanding. Pierre, essentially follows his own line of thought and defends his point of view. The second interesting aspect of the segment is that Pierre explains the phenomenon in terms of his observations of the behavior of light during the shadow sequence which he was previously so interested in, and therefore recalls so well. He assumes that there are similarities from one system to the other. During our conversation, Pierre gives himself the chance to explore his own line of thinking, even though the answer is not "correct," we are able to understand why he believes that it is.

> Mr. Ryan: Okay, what did you see?
> Pierre: The pencil looked like it was broken.
> Mr. Ryan: Absolutely right. Did you notice when the pencil hits the water line, it wasn't straight anymore? It looks like it's broken. And then, under water, [drawing on the overhead] it looked like... Pierre, since you noticed that, what is your explanation for the brokenness?
> Pierre: I think it is the roundness of the glass.

Ms. Shapiro: You are the one here who said, 'the pencil looked like it was broken,' and then you were asked to give the first answer for the first explanation. You said that it was the roundness of the glass. Was that answer accepted?
Pierre: (laughs) No.
Ms. Shapiro: How do you know that? He didn't say it was wrong.
Pierre: He didn't put it up on the screen or anything, and then he asked somebody else for the answer. So then I thought, maybe it was wrong.
Ms. Shapiro: What would have happened if it were right?
Pierre: He would have put it up on the screen. Usually when something is right, he puts it up on the screen.
Ms. Shapiro: So, you say that you think it was wrong at the time, but you have still written on the sheet that I gave the class afterwards that it is the, um, you've written here, "I still think that it is the roundness of the glass."
Pierre: Yeah.
Ms. Shapiro: How do you know that?
Pierre: That's a tough question. Well, you know that it curves around that way? Um, it's weird. (Laughs, looks

at drawing) Hmmm. (Sighs) Hmmm. Well, whenever there isn't any water in it, it's just straight, but when there is water in it, it just, huh! (Sighs, then laughs). I think that it's the deepness of the water. Yeah. And whenever you put it (the pencil) to the back, it makes it fat and it moves, it moves this. Now, I think that it's um, when you push it back, it makes it wide the pencil. It works just like that , it's just like one of those things that when you walk up your're big and when you walk down you're smaller. One of those things.

Ms. Shapiro: Are you talking about trick mirrors?

Pierre: Yeah. Like those and like the shadow things.

Ms. Shapiro: What do you mean? I'm not sure what you mean.

Pierre: Well, there's this thing, it's a box, right and it goes like that right and the floor's down like that and when you stand up like that, it's, um you're big, and when you stand down, you're small. It's like that with the shadows and like when you shine a flashlight. I didn't see these trick mirrors, but I've watched them on the show, "Three, Two, One, Contact." But this is really strange. (points to the beaker) I think there is something more that you gotta figure out. Something more to it, but I can't quite get what it is. It's like a maze or something like that. Mr. Ryan told the answer, but I just all of a sudden forget stuff.

Ms. Shapiro: Did anyone have the idea in class?

Pierre: Well, a couple of kids. But most kids, they, um Mr. Ryan explained the idea, but then everybody forgot about it.

Ms. Shapiro: Then everybody forgot about it. Do you mean that they actually did have it and you feel that you did understand it at one point?

Pierre: Yeah, I understood it pretty well, but then I forgot all about it . I'm just working very hard here and then all of a sudden I keep on forgetting about it.

Ms. Shapiro: I see. So it seems not to stay in your memory? Stay with you?

Pierre: Yeah. Something just seems to push it out. (laughs)

Ms. Shapiro: You don't recall then, Mr. Ryan's explanation at the time, but you did believe it at the time?

Pierre: Yeah, I did, I guess. I didn't understand it very well, but I did think that he was right. But I don't now.

Like Donnie, Pierre expresses the belief that he does not quite have all of the information. If he did have it, it would be like completing the "maze." In this view, all of the pieces would fit together and he would understand.

In the sequence presented, the value and importance of "doing it on your own" emerges as meaningful for Pierre. His great interest in and enjoyment of exploring the topic which is being studied formally in the clasroom setting but it appears that he might benefit by having greater freedom to explore the ideas which are of immediate interest to him as he is working. While Martin pursues topics of his own interest outside of school in a fairly random and disjointed manner, Pierre makes a more systematic effort to follow up on classroom activities and to find out more about the topic. Amy, in contrast, is interested only in what is being learned in class, and has no interest beyond the presentation of ideas in the classroom, grasping the requirements of the task before her and doing it successfully.

Reflecting on the Case Study Reports

An overall consideration of the case study reports brings to our attention a number of important issues regarding science instruction. A consideration of the differing orientations and needs of the individuals in the study brings important questions to be considered in a reflection on each child's situation. For example, even though Amy is the more "successful" student, is she really gaining an interest in science? Are we achieving some of the most important goals of science instruction with Amy? Is she experiencing the joy of discovery? Is she valuing of the pursuit of understanding? Is conceptual change the most important goal in science learning? Do we ignore Pierre's needs by focussing on and rewarding what is of interest to Mark and Amy? Do we recognize the interest in deep understanding that Donnie seeks, and do we know how to help her to attain it? As educators, we must also ask, how do we come to an understanding of why some ideas are more difficult for students than others to grasp when we leave out the individual's needs and interest in grasping concepts and focus upon concept change as the only goal that matters and is valued?

A reflection on the research approach of the study and the individuals of the study suggests that we will benefit from thinking more deeply about our ways of listening to children in the classroom and take into account the contribution of the child in his or her own efforts to construct meaning in science.

Chapter 7

THE DEEPER MEANING OF LISTENING: REFLECTING ON THE CASE STUDIES AND THE RESEARCH APPROACH

7.1 Introduction

Maxine Greene (1973) writes "no matter how the teacher conceives the human being, his primary task is to teach the young person to know" (p. 99). In educational practice, the traditional interpretation of teaching the young person to know has meant emphasis upon the acquisition of a body of knowledge or a set of facts. More recently in science education, with the emphasis upon students' alternate frameworks in science and mathematics, bringing about concept change in students has been considered by some to be a teaching goal of greater significance. The educator holding a constructivist orientation as conceived in the present research project extends the view of "teaching the person to know" to encouraging the student to take greater responsibility for his or her own learning. These changing views about science teaching are presented in Figure 7-1.

The individual case studies presented in Chapter 6, are designed to add perspective on the child's thoughts, feelings and intentions in learning as another important consideration as we seek to understand how we might best teach the child to know. The project attempts to understand how children's own patterns of thought and behavior affect their learning in science. The study has been designed to

Figure 7-1.

TOWARDS A CONSTRUCTIVIST CONCEPTION OF THE SCIENCE LEARNER AND SCIENCE TEACHING

	GOALS OF SCIENCE TEACHING	VIEW OF THE LEARNER	IMPLICATIONS FOR TEACHING
Trend I	Idea acquistion	The learner's mind is a blank slate.	Transmit scientists' ideas about natural phenomena to the learner.
Trend II	Idea change	The learner has ideas about the nature of phenomena.	Use strategies which identify the learner's ideas. Develop strategies which change students' ideas to scientists' ideas.
Trend III	Idea change. Awareness of learner approaches learning and ways of constructing meaning in science.	The learner has ideas about the nature of phenomena. The learner has thoughts and feelings about the experience of learning science in school. The learner has a unique and personal approach to science learning.	Conversation, listening and dialogue to understand the learner's ideas and approaches to learning science. Develop approaches which help students take greater responsibility for their own learning.

Some of the learner's ideas, expectations and feelings about science learning are included in the following:

- Ideas about what science is and what scientists do
- Ideas about the nature of the learning process
- Ideas and feelings about oneself as a science learner
- Ideas and feelings about the meaning and value of learning science in school
- Ideas and feelings about learning science with other children and with the teacher
- Ideas and feelings about past experiences about science learning
- Ideas and feelings about future experiences in science learning

provide awareness, insight and reflection on the processes whereby children create meaning in the classroom, that is, how they use materials and other resources to make sense of the learning environments which we create for them.

Dewey (1961) suggested that the learning process itself should build upon young people's "tendencies to make, to do, to create, to produce, whether in the form of utility or of art." In order to build upon these tendencies so that we may best guide students, we must first develop an awareness and understanding of what these tendencies are. The six case reports of young children learning science have documented individual orientiations to science learning as students constructed meaning, produced new insights and understandings and performed the tasks required of them in their unit on light.

7.2 Teachers and Students as Co-Architects of Learning: Towards a New Conception of What It Means To "Teach the Young Person to Know"

As has been discussed in earlier chapters, many studies and approaches undertaken in science education seek to characterize student ideas in science learning. The majority of these studies have attempted to determine the ideas held most commonly by a specified group of persons. Many of these studies have been based upon the conviction that teachers must move from the view of science learning as idea acquisition only to consider the important goal of science teaching to be that students change their own ideas about natural phenomena and accept scientists ideas about natural phenomena (Anderson and Smith, 1982). The fundamental stance of this viewpoint is that the process of idea change is a wholly rational affair (Posner and Strike, et al, 1982). To their credit, these studies have contributed enormously to our understanding of the points at which many students may "go wrong" in their thinking, and the suggestions provided for working with students may help many teachers to assist students to reflect on their thinking. However, the 'instructional fix' approach suggested by many of these studies may lead away from what may be deeper issues in learning science. As Appelman, et al. (1983) recognized, the challenges of science learning may run deeper:

> ...we are up against something rather deep in the relation between science and common sense; we are up against a barrier to teaching in the didactic mode which has hardly been recognized, or if recognized, has been seen mainly as a challenge to ingenuity in teaching rather than as a challenge to a deeper understanding of human learning.
>
> p. 5

George Kelly (1955) considered learning to be more than the simple rational changing of ideas. He considered it to be a creative, emotional, active, ongoing and rational affair. Personal Construct Theory was developed to assist in the understanding the person's way of viewing his or her circumstances, but also to assist the person in exploring potentialities, or alternatives which might be available to the individual who had run out of options, or who was experiencing difficulty and frustration.

7.3 Developing the Elements of Personal Orientation to Science Learning

This research project has looked not only at the general shape of student ideas about natural phenomena, but a commitment was made in the conduct of the research to listen to students; to understand their creative, emotional, social, and intellectual responses to phenomena and learning. The guiding questions of the study used to develop the case reports attempted to identify aspects of the children's contribution to the school learning experience. These guiding features both guided the development of the case reports and suggested some of the elements of the child's contribution which were important in the construction of knowledge in science. These questions were:

1. What are the children's ideas about the nature of light prior to the study?
2. What are students' previous experiences of and interest in the study of science in the elementary school program?
3. What are the children's views about the meaning and value of the study of science?
4. What are the children's views of themselves as learners of science?

5. What aspects of the study of the topic appear to be readily comprehended or accepted? What do students see as facilitating their understanding during the study of light? What types of learning activities do students consider most valuable?

6. Do the children experience puzzlement, difficulty or confusion during the study of the topic, light? What do the children themselves have to say about the difficulties encountered?

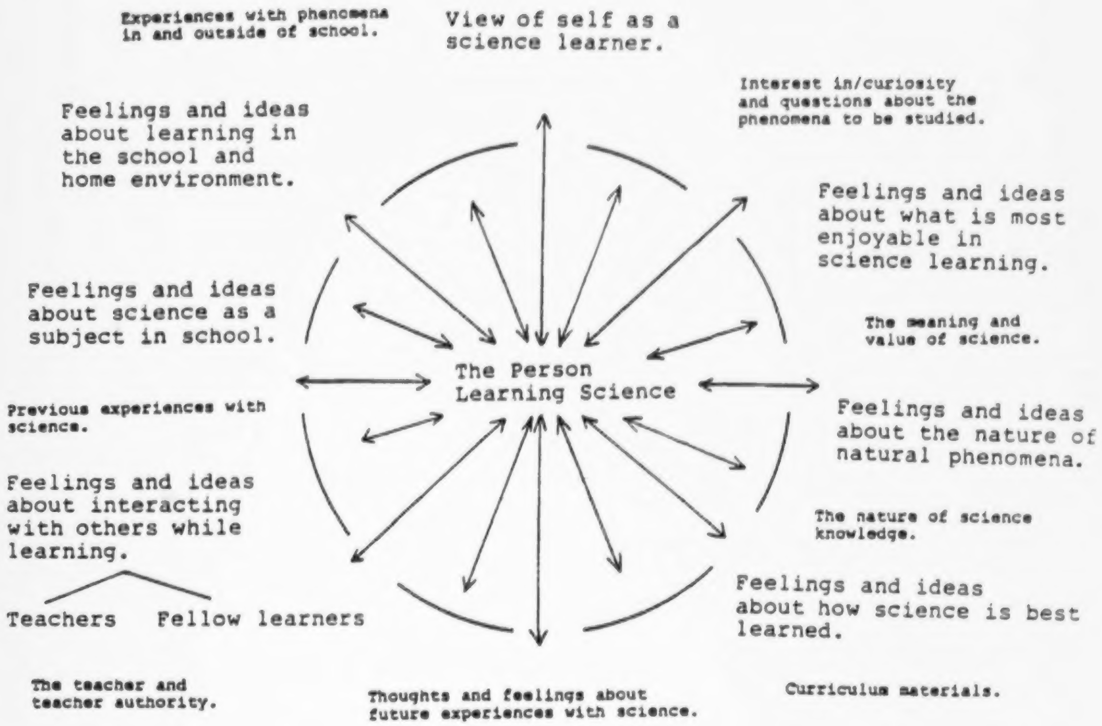
7. How does the child's approach or orientation to science study interact with the acquisition of ideas?

Discussion and reflection on the conversations with the children allowed the recognition of other elements of personal orientation to science learning providing insight into the patterns and the themes which emerged for each child in the case study reports. The important view of the child as active contributor to the learning experience is summarized in the model presented in Figure 7-2.

My attempt to portray the contributions made by the children to their own understanding reflected a shift in emphasis from children's ideas about phenomena to the interweaving of relationships between the child's mind and environment. Gregory Bateson (1979), an advocate of a new view of the nature of mind, argues that it is the relationship of objects and events to one another which should constitute our study and research efforts, not objects and events separately and of themselves. Personal orientation to science learning has been a construct developed and used to convey the interelationship of child

Figure 7-2.

Elements of the Child's Personal Orientation to Science Learning


Experiences with phenomena in and outside of school.
View of self as a science learner.
Interest in/curiosity and questions about the phenomena to be studied.
Feelings and ideas about learning in the school and home environment.
Feelings and ideas about what is most enjoyable in science learning.
Feelings and ideas about science as a subject in school.
The meaning and value of science.
The Person Learning Science
Previous experiences with science.
Feelings and ideas about the nature of natural phenomena.
Feelings and ideas about interacting with others while learning.
The nature of science knowledge.
Teachers
Fellow learners
Feelings and ideas about how science is best learned.
The teacher and teacher authority.
Thoughts and feelings about future experiences with science.
Curriculum materials.

The dotted lines which make up the circumference of the circle represent the permeable nature of the boundary between the person and his or her experiences with the external world.

Lines which cross this boundary pointing simultaneously away from the person and towards the person indicate the dynamic nature of the process of learning. The individual is both affected by the external environment and creates experience by interpreting through the personal lens of his or her personal orientation to science learning.

thought and school experiences.

The present work adds to our understanding of school science learning by demonstrating that not only does the child have his or her own ideas about natural phenomena, but that these ideas are also imbued with thoughts, feelings and attitudes about the nature of science knowledge, about science outside of school, about the nature of the learning process, about oneself as science learner about the teacher of science, about other students, and about the experience of being in school itself.

7.4 The Deeper Meaning of Listening -- The Essence of the Research Approach

John Holt (1967) wrote that the purposes of education would be best served if educators could learn to:

> ...look at children, patiently, repeatedly, respectfully, and to hold off making theories and judgments about them until they have in their minds what most of them do not now have--a reasonably accurate model of what children are like.
>
> p. 10

To observe well and to come to know the children we teach is, of course, a totally worthwhile endeavor. But to attempt to develop a "reasonably accurate model" of the child, we must recognize that when we "look" at children, each person looks through his or her own set of anticipations and expectations of the nature of the child.

Not only do we look in different ways, but we ourselves are a part of the child's experience as we are looking, and affect the child's experience by the very act of looking. The impact of the observer on the observed system has been one of the revolutionary recognitions of modern physics. It has been recognized as equally significant in the attempt to understand personal and social systems (Prigogine and Stengers, 1984). When we attempt to understand children, we look, we listen, and we also feel. We have our own ideas and experiences which come to bear upon and interact with what we see. Michael Scriven (1961) has written that when we attempt to understand others' approaches to experience, we do so through "attaching the facts of the particular case to the terminals of our own response system, i.e., our own personality (p. 61)." The attempt to understand requires that researchers and teachers become more self-conscious and _self_-aware as they listen to children. In the development of the case study reports, I have used elements of the technique of _verstehen_, referred to by Schutz (1967) as "the particular experiential form in which commonsense thinking takes cognizance of the social cultural world." Verstehen has been the approach used in seeking to interpret what another person intends by his or her actions and how the person perceives or conceives a situation. This aspect has involved my own reflection on what the experience is like for that other person.

In this study, the emphasis upon listening powerfully characterizes the approach which I as researcher have made in conversation with the children in the study. Conversation has been the main form of data gathering in the study. "Sensitive listening" has been the essence of the research attitude and my approach to the study has been one of friendship and caring. Since reflection was accomplished with the children the nature and quality of our relationship was crucial to the success of the study. As I became deeply involved in listening to, conversing with and sharing ideas with the children in this study to understand how they listen to and converse with the elementary science program, I thought about listening itself, what it means in authentic human encounter and what it means in teaching and in educational research. In the process I have discovered that when I truly listen to another human being, I listen with many aspects of myself. As I listened to each child, and as they listened to me, I became more aware of the ways that I gave him or her my attention, and how my manner invited the sharing of ideas and feelings. Was I listening like a caring friend, the elementary school teacher that I had been for so many years, or an educational researcher? It became clear that real listening is accomplished at many levels of response to the person who is speaking to us. Even though we may not be speaking as we listen, the act of listening conveys a message to the person who is speaking to us, who notices the ways that we listen. We listen with our eyes. We see the ways that the person speaks with us, their stance, their changing facial expression, their shifting on the chair or movements towards or away from us. We hear pauses, sighs, perhaps a laugh. When we sense that we are truly being listened to, that someone sincerely wants to hear our story, we tend to open up more to the listener, to tell more, to share more of our true selves. Talking with children, listening to children and being listened to by children has been the essence of my approach and findings in the research project. It has also meant recognizing and reflecting upon my own manner of listening to the children in the research project and has renewed my awareness of the pedagogic implications of ways that I listen to the students whom I teach.

Educators often expect that there is a greater responsibility for the student to listen to the teacher than the teacher to listen to the student. Students are often judged to be lacking in their listening skills. But we might profitably ask, how well do we listen to students for the purpose of understanding their interests, their stories, their ideas, their problems, their concerns. How might we better listen in order to know what we must do to guide them to understanding, empowerment and satisfaction and happiness in their work in school science? And if we listen well to our students might they become better listeners when we have something we would like to tell them?

As I have listened to each child in the study with the intention of understanding personal orientation to science learning, I found that I was not only hearing what the child was saying, not hearing only words, but each child was sharing with me their own personal struggle to understand in school science. The *strong and consistent pattern* of each person's struggle was an interesting surprise to me. As I reviewed and listened to the videotapes of group work, with an interest in understanding each person's individual approach to science learning, each child's struggle to learn took on a powerful new dignity and meaning for me. What might have seemed on the surface or to the casual observer to be "time-wasting" or "goofing off" became more clearly an expression of each person's approach to science learning. Each child was struggling to succeed, each in his or her own personal and individual way.

At times the child's personal orientation served the student to provide greater understanding and success in the classroom. Sometimes there were conflicting conceptions among children about the best way to approach learning tasks. The approaches of individuals within some groups clashed in their orientations and there were, at times, harsh words. Sometimes the ways of individuals clashed with the intentions of the teacher or the curriculum and there was frustration for the student or the teacher. But I found that as I listened with a view to understand how each individual strove to understand with his or her own set of anticipations and expectations for learning, each person striving emerged for me with a new integrity based upon the repeated patterns which I was observing and recording.

7.5 A Review of the Themes of Each Child's Personal Orientation to Science Learning

A summary of the individual themes of of each child's case report is provided in Table 7-1. This table is provided to help the reader review, revisit and reflect upon the six students' stories and experiences.

7.6 Idea Change and Approach to Subject Matter: Considering the Insights of Other Researchers

A number of research studies which have focussed upon differences in learner approaches to subject matter which parallel and contrast with the current study, adding to our understanding of the processes of student learning. In this section, the findings of two projects are linked with the present study. The first suggests a framework for analyzing types of idea change found when children are asked to replace their views about natural phenomena with scientists' ideas.

The second series of studies suggests that students take one of several approaches as they pursue the task of learning. This work implies that students can more effectively decide which type of approach is most useful

Table 7-1.

SUMMARY OF INDIVIDUAL THEMES IN THE CASE STUDY REPORTS

The expressive student who seeks full participation in the learning experience. Artistic-dramatic orientation.	Donnie	I.	The sense of never having "quite all of the answer" in science.
		II.	Enjoyment of full participation in the activity, particularly in making drawings and diagrams.
		III.	Enjoyment of speaking up in class -- the sense of participation and telling what she is "feeling" about the topic, making a personal contribution.
The 'boy of ideas.' Intellectual orientation.	Mark	I.	An orientation to working by himself to discover new ideas which perhaps diverge from the curriculum outline.
		II.	Values science knowledge as tentative explanation. Enjoys "hearing what science has to tell us," the ideas and content of science.
		III.	Assured self confidence as a science learner. The feeling that he is "getting all of it."
The consummate tinkerer. Physical involvement orientation.	Martin	I.	Enjoys expressing his ideas verbally and trying new ways to experiment with the materials which may not appear in the worksheet or task outline.
		II.	Enjoyment of physical involvement with the materials. The consummate tinkerer.
		III.	An interest in and need for social interaction while working with the worksheets and the materials.
The socialite. Appreciator of beauty. Aesthetic-social orientation.	Melody	I.	An aesthetic orientation. Enjoyment in and appreciation of the beauty of natural phenomena.
		II.	Anticipation that she usually does not and will not understand what she is supposed to do in the science lessons. Sees it as others' responsibility to tell her.
		III.	A social orientation. An interest in knowing what other students and groups are doing and thinking about the phenomena. An interest in receiving help from other students.
The student. Dedication to high achievement. Task orientation.	Amy	I.	A task orientation. Values academic success. An interest in completing the worksheet successfully.
		II.	An interest in the ways that science is best learned with less interest in the science content information itself.
The natural historian. Delighting in the details and wonder of phenomena. Factual information. A product orientation.	Pierre	I.	An orientation and interest in the content and ideas of science. Special interest in specific facts and details of topic areas. A natural historian.
		II.	Anxious when he does not know what he is supposed to do. Sometimes anxious and adamant when he does not agree with an idea presented by the teacher.
		III.	Interest and enjoyment in pursuing activities and investigations on his own.

for themselves.

Gilbert, Osborne and Fensham (1982) suggested that idea changes can be classified into at least five patterns of outcomes. The usefulness of these categories was explored for comparing and considering the changes in the ideas of the children in the study group. The categories suggested by Gilbert, Osborne and Fensham are as follows:

1. The Undisturbed Children's Science Outcome
   Some science language is incorporated to describe a viewpoint, but the viewpoint is essentially unaltered.

2. The Two Perspectives Outcome
   The content of the teacher's presentation or the curriculum content is learned for class worksheet or examination purposes, but the student maintains the view that the world does not really work in this way.

3. The Reinforced Outcome
   The original student viewpoint (though not the scientist's viewpoint) is reinforced. The child emerges more convinced of his or her own original viewpoint.

4. The Mixed Outcome
   Scientific ideas are learned, understood and appreciated, but the interrelationships among ideas are often not integrated and are held in contradictory ways. The learner's views become an amalgam of children's views and teacher's views.

5. The Unified Science Outcome
   A coherent scientific perspective is understood and is related to the workings of the child's environment. Gilbert et al., describe this outcome as "typical of the coherent scientist's perspective," and comment that it is "the outcome that all teachers wish to arise from their interaction with students.

Using this framework, I attempted to place the children in the study group into the categories suggested according to the outcomes of their ideas about the nature of light.

1.	The Undisturbed Outcome	Pierre
2.	The Two Perspectives Outcome	Melody Amy Martin Donnie
3.	The Reinforced Outcome	Pierre
4.	The Mixed Outcome	Melody Donnie Martin
5.	The Unified Science Outcome	Mark

Overlap in the categories existed for several of the students. Pierre, for example, became adamant in his view that certain of the ideas presented by Mr. Ryan are simply "wrong." This idea also served to strengthen his previous position about the behavior of light. Melody at times exemplified the Two Perspectives Outcome. This was particularly noticeable when she copied answers from others' papers without apparent interest in what she was writing down. She stated that she believed that the teacher was correct because being the teacher he must know the correct answer. But in conversations with Melody at other times, it was clear that she did not "really believe" that the world functions in the ways that Mr. Ryan suggested. At other times, Melody demonstrated that she had grasped some of the ideas presented by Mr. Ryan and used them to explain phenomena. Yet her statements were mixed with her own ideas about the nature of light.

Gilbert, Osborne and Fensham suggest that the aim of science teaching is best viewed as the development of "children's science" as contrasted wth "scientist's science."

> Traditionally, the goal of the development is scientist's science. This has proved to be an immense task that is often very incomplete even among so-called successful learners. As happens in many present science classes, we may have to be satisfied with largely undisturbed children's science as our outcome. A more modest and manageable goal in these cases would be to make these learners aware that there is another viewpoint, the scientist's viewpoint, which is useful to scientists and may have more general use also.
>
> p. 632

Mark is one of several students in the class who showed a tendency to value the potential of others' viewpoints to enhance his own understandings in science. Mark exemplified the characteristics of the category, the Unified Science Outcome, and was not only very successful in grasping ideas, but had a deep interest in the ideas of scientists.

A second set of research studies which added to understanding of student approach to subject matter emphasizes student "learning styles." (Brew, 1979; Marton and Svensson, 1979; Marton and Saljo, 1976a, 1976b, 1979; Ramsden, 1979; Entwistle, 1979; Biggs, 1979; Laurillard, 1979). Many of these studies categorize student approaches to learning. Other studies emphasize ways that students themselves may be encouraged to make decisions about the approaches which they will use to achieve their own best growth in learning.

In a study of the first type by Marton and Saljo (1976b), for example, two types of learners are distinguished. The authors, interested in the relationship between student processing strategies and the outcomes of learning established two categories: deep level processing and surface level processing. In the surface level approach, the student is described as holding a "reproductive" conception of learning. In deep level processing, the student attempts to grasp the deeper intents of subject matter content. In Marton and Saljo's study, student approaches to textbook study were analyzed. The authors asserted that those students who used a "reproductive" conception of learning failed to grasp the logic of the material being studied. Students placed in the deep level processing category were found to use a "vertical" approach to text. Following the argumentation of the text was important to these students and they subsequently grasped ideas.

The authors produced a second study based upon their findings which assumed that the typical learner is capable of working in either processing mode, and can make a decision about which mode is most appropriate to use. The question is not answered, however, as to why there were initial differences in student approach, given the same task. However, the main thrust of the final implications of Marton and Saljo's work is that students can be guided to reconsider the ways that they approach learning tasks.

> A common idea in these studies has been to observe and describe, in as great detail as possible, what characterizes a deep and a surface approach respectively in terms of the kind of learning that people engage in. On the basis of this knowledge, it ought to be possible to influence people who do not spontaneously adopt a deep approach to behave in a way similar to those who do in a given situation.
>
> p. 49

7.7 Some Difficulties Experienced By Children in the Classroom As a Whole in the Study of Light

A number of the difficulties which the students encountered with the topic, light, were experienced by students in the study group, but many were experienced by a large number of students in the classroom as a whole. These general areas of difficulty are described below:

Basing thinking wholly upon perceptual clues

Many students tended to base ideas and reasoning about light phenomena wholly on perceptual cues. Light was thought to exist only when its effects were visible. A student following this line of reasoning understandably had difficulty with ideas which require understanding of ideas about the reflection of non-visible light rays which pervade our environment, for example, refraction. The curriculum materials used by the class teacher in the present study may actually perpetuate this non-scientific understanding of light by engaging students in a series of activities in which experience are provided which use, as a constant point of reference, the visible beams of light which the children see emerging from the light box. The light box and its emerging beams were central features of almost all of the lesson activities.

No reference is made in the curriculum materials to the existence of and behavior of non-visible light rays which pervade the environment. Lack of reference to non-visible rays of light leaves students confused and grappling with two ideas about the nature of reflected light. Several children in the study spoke about light as the general experience of brightness. At other times, light is described as the separate and distinctive visible beams which were seen emerging from the light box.

Understanding Color: Personally Experiencing Ideas Versus Accepting Them

For most of the children, color was understood as a substance within an object despite the fact that Mr. Ryan provided the class with the scientific explanation of color vision. Beginning with ideas about the white light spectrum, he described how objects appear to us differently colored because they "push out" or "absorb" light rays from different areas of the light spectrum. These ideas were intriguing to students, but also proved confusing. In one of our conversations about color, Donnie pushed her finger against my sweater, complaining, "I don't see anything pushing out." As this kind of pushing is not observable, once again we are attempting to build upon a concept of non-perceptible reflecting and absorbing light rays which students cannot experience and must simply accept on faith. What also seems confusing to students is that pushing usually implies an observable act and this term is being used in a far more specialized way than has been explained to them. Another difficulty which emerged not reported in the research literature was the difficulty students had when asked to provide an explanation for an event. When asked to explain why a rainbow was observed when light is passed through a prism, for example, many students described what they saw rather than providing an explanation of the event.

Weird Words and Funny Language: Trouble with Terms

Many students in the study also had difficulty using terms which refer to scientific notions about light phenomena on the one hand, but which have commonly accepted, real world meanings which are something quite differnt for students. The use of the term, "push" described in the discussion of color vision is one example of this problem.

Saying that light "bends" is another example which was interpreted by most students to mean bending as a coat hanger might be bent at a distinct angle. Many children said that bending occurred when light beams hit and reflected at an angle from a mirror. Another example is the use of the simple term, reflection, which was thought by most students to mean that which is seen when one looks in the mirror. During lessons on light the term reflection was consistently defined and reviewed for students in precisely this way, further confounding the development of the idea that nonvisible beams of light reflect off all objects. In class discussion, however, many children demonstrated that they had "learned" that the moon reflects light from the sun, thereby allowing us to see the moon. This idea was presented on the program, "Sesame Street," and several children commented that thery had originally become aware of the idea when it was presented in a poem in the popular program, "Free to Be You and Me."

The Sun and the Moon

The Sun is filled with shining light
It blazes far and wide
The Moon reflects the sunlight back
But has no light inside.

I think I'd rather be the Sun
That shines so bold and bright
Than be the Moon, that only glows
With someone else's light.

Elaine Laron, Age 8

As a result, many students stated that light reflects from the moon rather than being produced by it. But it was clear in subsequent conversations that ideas concerning light rays reflecting from light source to object, and then to the earth was not an idea which was extended to other objects in the environment.

At one point in the term, I taught a lesson on reflecting light in an effort to explore student difficulty with the idea of reflecting light. I brought into class a light meter and a reflecting parasol loaned by a professonal photographer. With the large class group, we measured the amount of light reflecting off various objects and environments. In addition, we used the reflecting parasol to show how the amount of light reflection could be altered. The discussions which followed showed that although the idea was grasped by some students in the class, it was not generally grasped by the majority of students. Seven children in the class emerged with an understanding of the behavior of non-visible light rays, but the majority of students told me that they believed that the light meter indicated whether it was dark or light. This is, of course, partially correct, but the deeper and more complete understanding remained that the light meter measures the non-visible light rays reflecting off objects, the key idea in the unit on Light.

Despite the fact that the difficulties mentioned above were pervasive and experienced by many of the children, a survey administered to the entire class showed that many of the children did in fact, grasp aspects of the scientific explanations which were offered to them. The study suggests that elements of the individual's personal orientation to learning science considerably affects the development of student ideas in science and the student's desire to continue learning science. Students approach science learning with different expectations and anticipations. They listen to, interact with one another and participate in the activities of science learning in different ways based upon these anticipations and expectations. They have differing views of themselves as successful science learners. They have different views about the nature of science knowledge, their understanding of what their teacher is trying to accomplish with them, and how much responsibility they should be taking for their own learning. They have also had different experiences with learning science in the past. There are different aspects of the science lesson which interest them and which they like to participate in. They see different purposes for studying the topics assigned. The student's personal orientation to learning science appears to have an important impact upon the development of ideas in science, the child's delight in scientific inquiry and his or her interest in persisting in the study of science beyond the elementary school years.

7.8 A Selected Review of Some Content Understandings at the Completion of the Unit and The Interplay of Changing Ideas With Personal Orientation Themes

Throughout the study and at the completion of the unit, I distributed written surveys to all of the students in the class and interviewed the six children in the study to gather information on the change in student ideas about the nature of light. Slightly different problems and instances were presented to students in the final survey. Each student in the study group was also interviewed to discuss the responses and comments made for each question.

The surveys and the results of my conversations with students indicated that three students in the study group either completely grasped or showed the beginnings of a grasp of the idea that vision is possible because light beams reflect off objects and into our eyes. Mark grasped this concept completely and used it to build the concept, refraction. Melody and Dawn used this idea to explain reflection on _some_ occasions, but did not appear to grasp the concept sufficiently to use it to build an understanding of the concept, refraction. I found also that students' learning outcomes were related to personal orientation to science learning as described in the case study reports. Selected portions of the the survey are presented in Tables 7-2 through 7-5, with comments on noteworthy aspects of each child's performance. The complete survey is located in Appendix B.

Table 7-2.

Summary of Student Ideas About Light At the Conclusion of the Study

In these examples from one of the final evaluations of student ideas, the children were asked to draw arrows to show how the light from the sun allows the girl to see the tree. The second drawing checks for a deeper understanding of the concept. Here the student must apply his or her understanding.

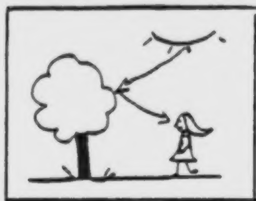
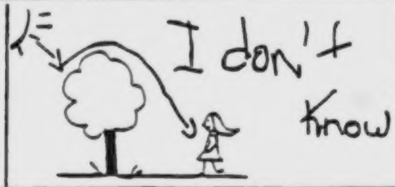
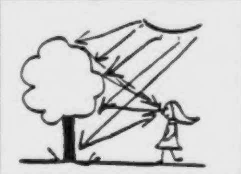
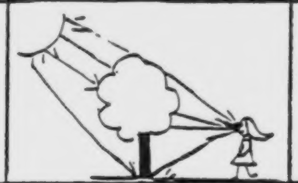
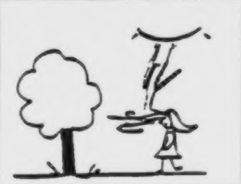
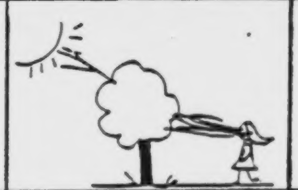
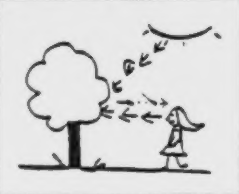
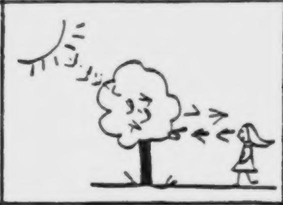
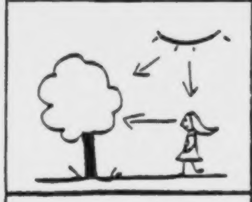
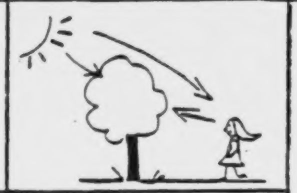
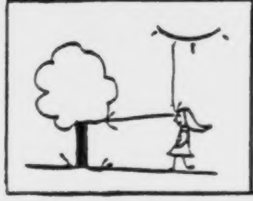
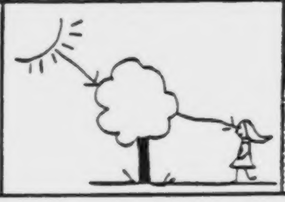
		DONNIE is able to reproduce the scientist's conception, but is not able to transfer her understanding to a new situation.
		MARK is able to draw in and discuss the scientist's conception in these and in all of the examples which are given to him.
		MARTIN'S diagram is confusing. In conversation he shows some grasp of the concept, but is not able to demonstrate understanding in these examples.
		MELODY draws and speaks of the scientist's conception in both examples, but in the discussion with her, I find that she does not always use the scientist's conception.
		Despite their arrows pointing from the sun to the tree, both AMY and PIERRE hold to their original views that the girl sees the tree because the light is falling on her.
		

Table 7-3.

Summary of Student Ideas About the Formation of Rainbows

Question: Everyone saw rainbows when we looked through the prisms. How are rainbows formed?

Colors are inside the prism, the light shines on the prism and the colors are brought out, you need light for the rainbow to form.	Despite her incorrect response, DONNIE has made the attempt to provide a fairly sophisticated explanation.
The prism bends and slow down the light so much that it splits the light into it colors.	MARK has grasped and conveys some of the scientist's view which was put forward by Mr. Ryan.
Threw the prisam	MARTIN provides a partial description rather than an explanation.
Im not Sure but I think light gose in to the prism and the angel of the glass makes a rainbow.	Some elements of MELODY'S response show potential for her understanding of the scientist's view, yet she includes a statement about her own sense of inadequacy in providing the answer.
I dont know how they are formed I don't know	Despite Mr. Ryan's explanation, AMY and PIERRE say that they do not know how' rainbows are formed and do not offer even a tentative explanation.

Table 7-4.

Summary of Student Explanations of Refraction

Question: What is your explanation for the unusual appearance of the pencil in a beaker of water?

DONNIE

Donnie tells me that she has not answered this question because she still feels that she does not have "all the ideas about it right."

MARK

The water is bending the light from the pencil so it looks broken

Mark has demonstrated a grasp of the concept in this and in many other examples which I have given to him.

MARTIN

The water axs Like a mag nifigher

MELODY

The water makes the bottom half bigger

AMY

The water acts like a Magnifier.

Martin, Melody and Amy continue to put forward a correct, but more descriptive response, rather than an explanation.

PIERRE

The roundness of the glass

Pierre continues to insist that his original view is correct.

Table 7-5.

Summary of Student Reflections On the Light Unit

The personal orientations of students presented in the case study reports continue to be reflected in their comments about which experiences they most enjoyed, what they continue to wonder about, and what they found most difficult to understand.

To review these personal orientation themes, refer to Table 7-1.

Question 1: What I liked most about the light unit was...

DONNIE

the neet
and different object, drawing and
experimenting.

MARK

I liked
experamenting.

MARTIN

expe-
rement

MELODY

I got
to experament with things like
light

AMY

doing
experiments and I liked to
use the equiment especially the colored cards.

PIERRE

I Liked
almost everything. It is great

Table 7-5. (Continued)

Question 2: I am still wondering...

DONNIE	how the prism makes rainbows and how it makes things up when it down and down when its up.
MARK	
MARTIN	The Lignt Meaten
MELODY	I am not wondering about anything else.
AMY	what makes rainbows come out of the prism.
PIERRE	Why the pencil gets fat in the becker of water.

Figure 7-5. (Continued)

Question 3: What I found difficult to understand was...

DONNIE	how the beaker of water makes the light beams cross.
MARK	
MARTIN	prisim
MELODY	light bends how
AMY	some of the questions on the sheet.
PIERRE	how the prisim made rainbows when you shine the light throgh it.

The present study has described some of the ways that children represent learning to themselves during the study of light. I have delineated themes in student approaches to learning tasks and have attempted to demonstrate how personal orientation to science learning is related to student interaction and development of ideas in science. An important next phase in this work would involve the encouragement of teachers to recognize student approaches to science learning, and would also encourage students to recognize their own approaches, to look at other approaches and to reconsider the effectiveness of their own efforts to learn. A consideration, then, from a constructivist point of view of the shape of a program which helps children construct meaning in the classroom is considered in the final chapter of the thesis.

Chapter 8

SOME THEMATIC REFLECTIONS ON THE CASE REPORTS

8.1 Introduction

Further reflection on the individual children's personal orientation to science learning is undertaken in Chapter 8. Elements of personal orientation to science learning are used as themes to reconsider, contrast and compare students' grasp of ideas and experiences as they studied the topic light. The themes selected for revisiting the case studies are:

- 8.2 View of Self as A Science Learner
- 8.3 Views on Learning Science with the Teacher--Teacher Authority
    - 8.3.1 On Taking Responsibility for One's Own Learning
    - 8.3.2 The Meaning of "Getting Help"
- 8.4 Views on Students Doing Science and Scientists Doing Science
- 8.5 Views on Science Learning: Past, Present, Future
- 8.6 Interest in Science Learning Outside of the Classroom

8.2 View of Self as A Science Learner

Conversation with Donnie was particularly useful in helping to understand how a student's development of a view of herself as science learner creates anticipations and expectations about her participation in science and science learning. Donnie was aware that she was not grasping many of the ideas that Mr. Ryan was presenting to the class. Because of her intense interest in fully participating in the lessons and in the discussion, she frequently made the effort to put forward her ideas in class. As a result, her personal struggle as she attempted to understand was very apparent to Mr. Ryan. Donnie thought seriously and carefully about the problems presented in class. She appeared quite disturbed by any questions which she could not answer. As noted in her case report, some of the questions Donnie asked are similar to questions asked by physicists themselves in the search for fundamental understanding. Donnie often commented that she felt that she was not understanding the nature of light "at all." She described the continuing feeling that "I never quite get all of it." In fact, Donnie did demonstrate a partial grasp of the difficult concept, refraction. But she moved back and forth in her understanding between the use of one explanation at one time for refraction phenomena and another explanation at another time. This approach parallels the scientist's use of one explanation at one time, another explanation at another time, depending on the purposes of an experiment, but such an approach is usually not rewarded in the school science setting. Mr. Ryan commented that he found it "a bit frustrating" that Donnie was not putting ideas together for herself. He felt that he had to somehow do this for her. There was no opportunity for Donnie to recognize that through her personal approach to learning she was actually thinking at a very sophisticated level, and was much closer to understanding than she realized.

The learning process is complex. Making connections among ideas is a gradual process requiring time, experience with materials and an amount of faith in science authority. Often children make incomplete connections and have no oppportunity for continuing discussion or extended experiences with materials. For many children, or for Donnie, the struggle to understand can lead to a feeling of emptiness and incompleteness. Donnie's own efforts to put ideas together was not positively recognized and encouraged. She did not see her own struggle as beneficial nor did she find satisfaction in overcoming the challenge. Her struggle had led to a lowered sense of the possibility of being a successful science learner, and on many occasions she expressed discouragement and despair. Donnie wondered why she was not understanding when others seemed to be. Her comment was that science "used to be fun" and that she felt that she had understood more in the past in science than as the years progressed. It seemed that Donnie's view of herself as science learner was unnecessarily negative. It perpetuated a sense of ineptness which she felt about herself and which characterized her ongoing experiences. Donnie and her teacher might find it benefical to become more aware of the powerful effects of this view of herself as a science learner.

Mark held a very positive sense of himself as a science learner. It did not bother him when fellow students did not pay attention to some of the ideas and suggestions which he posed as solutions to problems posed in class. Mark seemed encouraged by his successes, which seemed to spur him on to interest in both what Mr. Ryan had to say and in how he approched the activities and the curriculum materials. He approached the science activities confidently and seemed convinced that he could solve the problems presented to him. Mark also expressed that view that he was often able to help other students to grasp ideas and see problems in new ways. The only problem which Mark experienced in science learning was that the pace of the lessons was often too slow for him. When he put forward his construct, "Mr. Ryan is talking but you're not really listening," Mark told me that he often did not listen to procedural comments made by Mr. Ryan and often felt anxious to move on with the activities. Although Mark's self confidence was matched by success in his studies, this was not necessarily the case with other students.

Martin spoke often of a strong confidence in his ability to do well in Science. He expressed an almost grandiose view of his superior ability to find solutions to problems which had been difficult for other students. He told me that on one occasion during science he performed all of the activities and the other kids simply copied what he had done. From my observation, this, in fact, did happen often. but Martin was also very reluctant to listen to another person's idea or viewpoint regarding the manipulation of equipment. At the same time, Martin struggled with the reading and writing required to complete the worksheets. His difficulty with this aspect of the lesson slowed him down. This difficulty was at the root of several incidents in which he became frustrated with the experience and his inability to acomplish as much as he would like to. On these occasions, he would often reject the lesson.

Melody's sense of herself as science learner was quite negative, even though she enjoyed Science class a great deal. She believed that she "never understood" what she was supposed to do in science. This view seemed to keep her from Melody from trying to figure out the solutions to problems on her own, but because she sought so much assistance from others in science, Melody demonstrated the beginnings of understanding of some of the ideas presented by Mr. Ryan in class. Despite the fairly negative sense of herself as successful science learner, Melody told me that she very much looked forward to future studies in Science.

Amy's sense of herself as science learner was fairly positive. She believed that she was an effective student and that and that she was perceived as competent by Mr. Ryan. Both views were accurate. However Amy frequently had the correct response on paper only and did not recall the main ideas developed in the lessons. Amy told me that she believed that she would continue to do well in her future work in science.

Pierre participated in two different worlds of science learning. The first world was his own. Here he was "principal investigator" in his pursuit of studies about the natural world which held a continuing and deep interest for him. In this world he was confident, informed, and in charge of his own learning. But in the second world, the world of school science learning, Pierre pursued topics which were not as interesting to him. He saw himself as a less capable student here, as one who rarely grasped concepts. In this world, he found his teacher presenting ideas which he did not agree with and which he could not accept. In this world, Pierre was anxious about his performance, and though he wanted to do well very badly, he expected that he would probably not do well in science. Pierre would sometimes give up on tasks which were too difficult. I was left feeling deeply concerned that the great joy which Pierre expressed about learning science may be destroyed in the science classes of his near future.

8.3 Views on Learning Science with the Teacher--Teacher Authority

In the case study reports, it can be seen that the idea that light rays continually reflect from non-light absorbing surfaces caused many students great difficulty. Pierre insisted in conversation that the teacher was simply wrong in presenting this idea. Amy, Martin and Melody suggested that the idea was "strange," "confusing," or "didn't make sense," but they did acknowledge that the teacher had the authority to make these statements. They expressed the view that Mr. Ryan had studied the topic, that he _was the teacher_, and therefore he must be correct. Amy, Martin, and Melody did not question the veracity of the statement but stated that it was difficult to accept.

Melody showed an interesting attitude and way of thinking which was repeated whenever we discussed an idea which didn't immediately make sense to her. She would say that an idea which seemed unusual probably wasn't true, but that it "could be" true." She suggested that she could consider the possibility of truth, but the idea seemed beyond her ever really knowing for certain. This view is analogous to the position of the agnostic, that the human mind is not capable of grasping certain understandings. At the same time Melody put forward the view that Mr. Ryan's job as her teacher was to tell her what she was supposed to do and what she was supposed to know. She appeared to believe that it was largely Mr. Ryan's responsibility to be sure that she is understanding.

Donnie's situation and approach were different. She wavered at various points in our discussions between stating to me the truth of the teacher's statement, then questioning his view and making incorrect use of the ideas she had previously indicated that she had believed. Mark, on the other hand, accepted Mr. Ryan's statements completely and immediately. He used them in the development of further ideas, as in the refraction example.

I asked the students who said that they believed Mr. Ryan's statements, how it was that they knew that what Mr. Ryan was telling them was correct. Mark said simply "because he's the teacher, he's taken light in college and he tells us what he knows." Martin's comment was less consistent with my observations of his behavior. It was was edged with hostility, "Well like, what the teacher says, goes, right?" Martin seemed to be experimenting with this idea in his own social and learning life in school. Sometimes the notion of teacher authority was quite acceptable to him, at other times he resented and challenged it. Martin's conflict was reflected in his interaction with Mr. Ryan and the material presented in the light unit throughout the study. Martin's conflict caused both teacher and student frustration.

Although Amy did not always agree with Mr. Ryan's viewpoint, she seemed to find it to her greater advantage to accept his viewpoint at least for the time it was presented, and long enough to place it on her worksheet. It was particularly significant to me, in talking with Amy, to discover that some of her own ideas were often revealed to her as if for the first time in some of our conversations. Amy had a very fine ability to think deeply about the ideas of the lesson, but her greater interest in being an academic success actually thwarted the development of deeper thinking about the content.

All of the children believed that Mr. Ryan had probably written the worksheets which they had been given. Martin believed that they could also have been written by another teacher in the school and that Mr. Ryan had borrowed them.

When I asked the students who they thought selected the topics which they studied in science, all of the students said that they believed that it was Mr. Ryan. Pierre added that "probably all the teachers at the school get together at some time so that they would not teach the same things, but still they do sometimes anyway, like in grade three, we already studied light and now we have it again."

8.3.2 On Taking Responsibility for Learning

As noted in Donnie's case report, as I began to understand Donnie's personal orientation to science learning, it seemed that part of her negative view of herself as learner was created by actually taking too much personal responsibility for her own learning. Although she listened carefully in class and participated in class discussion, Donnie seemed to consider the burden and responsibility for putting ideas together as something which she, by her own experience, actions and thinking should be able to do in science.

Amy also had a great sense of her own responsibility for learning in school. But Amy's sense of responsibility did not include concern for the deeper grasping of ideas which Donnie showed. Amy's sense of responsibility was in completing the tasks before her accurately and promptly. She did very well on the science worksheets. Because of Amy's consistent success she was regarded by Mr. Ryan as the top student in the class. Yet she showed a very poor grasp of the concepts of the lesson and an unawakened understanding of her own ability to consider ideas in science. Despite her success in science, Amy appeared uninterested in most of the science topics studied.

As noted in his case report, Martin spoke of his great enjoyment of science, and considered that he had strong ability in this subject area. Science activities appeared to give Martin some relief from negative experiences in school learning built up from a history of frustration in school due to his great difficulty with reading and writing. Though Martin was truly talented in the physical manipulation of materials, he often went in his own direction in science, sometimes missing completely the thrust or point of the lesson because he had not read or understood the worksheet or Mr. Ryan's instructions. Martin's sense of responsibility for his own learning seemed very strong and could perhaps have been further enhanced by helping him to seek better strategies for understanding what was to be accomplished during each activity session.

Mark's willingness and ability to accept and retain the ideas which Mr. Ryan put forward in science class demonstrated another view of responsibility for learning. Because Mark did not see the need to experience each new idea for himself before accepting it, he was able to take the responsibility for learning seriously, but, with less anxiety than his fellow students. For Mark, the 'burden' of the proof of ideas rested with scientists as personified by Mr. Ryan rather than with himself.

8.3.3 The Meaning of "Getting Help"

"What are you supposed to do?" "What's this word?" "What do you write here?" "What's supposed to happen?" Procedural questions, by count, were the most numerous of the help requests used by the children in the study. But if such questions are only to be categorized and counted, the important relationship between the child's personal orientation to science learning and his or her grasp of ideas might be missed. In this section, the meanings of the theme, 'Getting Help' are considered for the children in the study group.

The theme, 'Getting Help' interweaves with the child's sense of self as a science learner and ideas about responsibility for learning in science. For some students, asking for help seemed to be an embarrassing, frustrating and alienating experience. Some avoided asking for help, keeping concepts and ideas at the level of dilemma rather than risk what for them was a painful experience. Other children were able to ask for assistance in ways that facilitated and expedited the learning process. Asking for help effectively appeared to provide these students with an enlivening, more satisfying experience in science.

For Martin, asking for help meant, at times, the admission to others that he had a great deal of academic difficulty. It was often Amy who called him a "dummy" at times when he had asked questions which were simple and obvious to her. On several occasions I noticed that Martin avoided asking questions about what was written on the worksheet. He would simply continue working with the equipment and materials until he discovered a relationship or insight of his own. In one instance cited in the case report, because Martin persisted in pursuing his own experience with the materials, he waited so long before asking for help that he nearly missed the observation that light beams cross when viewed through a beaker filled with water. This observation was the basis of the development of the idea that light rays bend at different angles through different types of liquid. It was not until Amy insisted that Martin consider the observation when Mr. Ryan came over to his group, that Martin appeared to feel comfortable asking for help. Mr. Ryan guided him through the activity, and Martin asked him questions about the set-up of equipment. Although Amy and Martin often teamed together to complete a task, Amy frequently belittled Martin for his impulsiveness and lack of attention to detail. Yet Amy often benefitted from Martin's cleverness in finding the solutions to problems posed in the activities. In one example, students were asked to discover several ways of reflecting light rays off a mirror and around a book. Martin discovered several ways to make this happen. But during this activity, when Amy belittled him, he became frustrated, angry, and moved quickly and loudly away from Amy and the assigned task.

As noted in the case study report, Martin did value a special form of interaction with Mr. Ryan in science which he referred to as "giving clues to the correct answer but not giving the answer." Martin valued "getting help" from Mr. Ryan because the nature of Mr. Ryan's guidance allowed him the satisfying experience of solving problems on his own.

Melody, in contrast, never hesitated to seek answers to questions on the worksheet directly from others. The significance of 'getting help' for Melody appeared to be largely in the social experience of asking, not in finding ways to understand ideas. Understanding the concept was secondary to the experience of engaging in talk with the other children. But when Melody went to "get help" she usually spoke with fellow students about concerns irrelevant to science, often to the great annoyance of her fellow classmates, and always to the great annoyance of Mr. Ryan. Because finding out what she was supposed to do in science seemed secondary in Melody's search for "help," she did not appear to be concerned when she did not have the correct answers to questions. Melody told me that she particularly liked science and subjects in which there were group activities because "I know my friends will help me."

I did not observe Melody ask Mr. Ryan directly for help on a single occasion during in the time that I was in the classroom. She did often ask students in her activity group for help, but she was more often than not absent from her activity group when I wanted to observe her working. I followed or searched out Melody on several of these occasions and discovered her talking with students in other groups. When I approached to ask her what she was doing, she usually explained to me that she was "getting help."

Although it was clear in my conversations with Melody during the unit, that she had no particular interest in light as a topic of study, it is noteworthy that Melody was one of the few students who was able to very clearly provide an explanation of how it was that the pencil in a beaker of water appeared to be broken. It appeared that it was because of, not despite Melody's social activity, that she was able to grasp some of the ideas presented. Melody's situation contrasts with Amy's, who rarely required help, but, who in fact, did have the correct answers on her worksheet. Amy had no grasp of the ideas of reflection or refraction, while Melody did have some grasp of these ideas. Melody's view of herself as a science learner was that of a person who never understands seems an unfortunate and inaccurate representation of her ability. Her view of Mr. Ryan as someone who should be telling her what to do likely contributes to the negative interaction which she so often has with him. She is not aware that he does not see his role in the same way. In Melody's Repertory Grid Conversation, "knowing how to do it" is stated far less frequently as a response in her review of the 37 activities than "You can't understand what you're supposed to do." This is revealed by a large number of 4's and 5's which show greater identification with the right side of the construct pole.

I observed Donnie ask Mr. Ryan for help on numerous occasions. I was surprised that despite Donnie's persistent efforts to secure help when she does not understand, she spoke very negatively of the experience of asking for help. She told me that Mr. Ryan "usually gets mad" when she asked him a question and that she frequently "felt embarrassed" when she "didn't know the answer to something" that Mr. Ryan seemed to indicate that he thought she ought to know. During the Repertory Grid construct elicitation session, Donnie used "Embarrassed--Just about to get into trouble" to describe this feeling contrasting it with the more positive, "Knowing just what to do." The science experiences which Donnie most closely associated with this construct (rating 4 or 5) were related to asking for help or needing help were the following:

4. Mr. Ryan tell us what we are supposed to do.
10. Mr. Ryan tells me what I am supposed to do.
14. I don't understand what I am supposed to do.
15. Kids are goofing around during the activity.
16. I ask the teacher what I am supposed to do.
24. I ask somebody else for help.
27. I don't get the answers I am supposed to.
28. Mr. Ryan gives me a hint about the right answer.
32. Some people understand things that I don't.
36. I'm having trouble reading the worksheet.

As reported in Donnie's case study, Mr. Ryan also commented negatively on Donnie's requests for help. He did not seem aware that his annoyance may have been contributing to her sense of frustration. Greater awareness of Donnie's views on asking for help in science would have helped him to guide her to ask more useful questions. With 33 students in his classroom, many demands were made on Mr. Ryan. He occasionally found many of the childrens' questions repetitive and annoying. On one afternoon, while the children were cleaning up their science materials and were leaving for home, John Ryan approached me:

John: I just can't fathom the level of questions that were asked in this activity!
Bonnie: What do you mean?
John: Well, like 'What do you do?' 'What am I supposed to do?' They just don't seem to take the responsibility to figure it out. I thought I had it clearly spelled out. I went over it before they got to work. Here is what you are to do, no, just let's do it...but so many came up to me and said, 'What am I supposed to do?' Like you figure it out for me. There, just, where is the motivation to figure it out for themselves?
Bonnie: I wonder what was the reason for that.
John: I think some of them are just plain lazy. Well, it doesn't come from all quarters, that's for sure. Some of the kids went ahead and did it.
Bonnie: There seemed to be a lot of 'messing about' in this activity.
John: Yeah, I guess I should have let them have the time to do that...but they took it anyway, didn't they? First of all, though, there are just too many kids to work with. When I sit down with one person and go over the ideas I begin to see the sparkle in their eye and when they really begin to get something. There are just too many of them who jsut find it easier to try to get me to tell them what to do, like 'here, you tell me' than to try to figure it out on their own.
Bonnie: I think that the reading level of the worksheets is beyond many of them. It's just easier to ask you to read it. Words like arrangement, procedure are very difficult for Martin. I think that he would rather just move ahead with working with the equipment. Also, did you notice that you told them to use the beaker and to make comparisons? The worksheet did not ask them to do that. That really threw Donnie, and several others.
John: Are you getting all of this down? I think Stephanie and Andy (district elementary science supervisors) should know about these things. Are you going to give a report to them?

Although the curriculum material did contain numerous terms and phrases which were very difficult for students, it seemed that students' personal approaches and views about asking for help are significant and useful areas for reflection for both teachers and the students. Mr. Ryan's practice of having the children correct their own worksheets at the end of each period did not allow him to gain insight into the types of errors which students were consistently making, and the problems which individuals perhaps were having over and over again with the material. This understanding would contribute to Mr. Ryan's grasp of the type of help students needed and would be asking for.

Some of the children in the study saw helping as something which they more consistently 'gave' rather than received. This was the case for Amy, whom students approached regularly for help, but many children simply copied from her in the end. This was upsetting to Amy and she complained about it often.

Martin believed that at times he provided help to "everyone." He told me, "I do all of the activities and stuff and everyone else just writes down what I find out." Though this was true on several occasions that I observed, it seemed that Martin would also have benefitted from realizing that he quite often was working with materials without knowing what the task was that was to be accomplished.

'Giving help' became a significant theme in the exploration of Pierre's experience. Pierre thought of himself as a science learner who usually required the assistance of others to read the worksheets in school science learning, and generally in understanding what to do in science.

The person who helped Pierre most often was Kim. Pierre told me that he liked working with Kim.

> Kim is like working with a teacher. He knows what to do and always helps me with the answer.

During the lesson on shadows and reflection, Pierre found himself working alone while his partner, Kim, ran an errand for Mr. Ryan. During Kim's absence, Pierre read the worksheet himself and began to experiment with the materials to determine the lengths of pencil shadows placed at different angles. Pierre worked quickly and had nearly completed the worksheet when Kim returned to the classroom. But upon his return, Kim and many of the students in the groups near Pierre had difficulty with the activity. It was a very new experience for Pierre to be one of the few students in the classroom who was able to understand and perform the activity. Pierre enthusiastically commented to me as we reviewed the videotape:

> This time he couldn't figure out what to do and I could. So I was like the teacher this time to him and I really knew by myself what he... what it was that he couldn't figure out. So I helped him this time.

Pierre seemed delighted and surprised by this experience, for it was not only Kim who asked him for help, but several other students in the area. The experience seemed to sharpen and highlight the content for Pierre.

On another occasion, I had arranged the videocamera to record Pierre individually. I then moved walked away from the camera to another group so as not to distract him. On reviewing the tape I observed a scene in which Pierre appeared surprised and even startled by his own discovery of light reflecting from a ruler with which he had been casually experimenting on his own. Pierre was sitting by himself in front of the light box, using various objects in an attempt to try to reflect light rays. He spoke aloud to himself:

> An eraser. Put it here. Hey. Light's going off it. What about the ruler? There. Hey? Light reflects off a ruler? Hey! Light reflects off a ruler!

Pierre seemed very startled by this insight, as if he was not sure what to do with it or whether or not it was correct. He looked around for someone to share his discovery with, but found no one. I noticed freshly how valuable the experience of sharing one's own competence and discoveries with other students was in the students' joy in learning. It also seemed that Pierre might benefit from valuing his own wisdom, developing an understanding that some of his best help could actually come from himself, that one of the greatest resources for help in learning which we have is our very own self. Our own thoughts, ideas and discoveries can provide insights and provide a great sense of accomplishment. This seemed an extremely important understanding for Pierre to gain in his effort to learn science and could potentially enhance the great joy which he took in learning science.

8.4 Views on 'Students Doing Science' and 'Scientists Doing Science'

Late in the unit of study one of the science periods was given up to allow a visitor to the school to speak with the class. The visitor was Monica Hughes, nationally known children's science fiction writer. She shared with the children the story of how she had become a science fiction writer and discussed the process of creating her most recent science fiction story. I spoke with the students in the study group following this presentation. Many of the children had read her books, which have received acclaim in Canada and abroad.

Donnie told me that she didn't like science fiction. She preferred a book "which is either just all story or all true because I keep getting mixed up about what is true and what isn't. I have trouble keeping track of what happens next and what happened before in those kind of books." It seemed that Donnie's feelings about not quite having all of the details in science lessons extended to her reading of science fiction.

Amy had read all of the author's books and commented that "she writes them to make you feel like you are really there. I really like her books." Amy seemed to have no difficulty keeping track of the details of the science stories which she read.

Mark said that he liked science fiction stories "like 'Raiders of the Lost Ark,' where there's was lots of adventure and stuff and where they use science to get out of things like when they used the light on the pyramid to open a secret vault." Martin also said that he enjoyed it "when science stuff was used in stories, because then you can learn more about how things work." Pierre said that he liked science fiction "because science is in everything," but he preferred to read "books about real things like how the earth was formed, and how rocket ships work."

During this time, the children were writing science fiction stories in their language class and were able to relate the author's talk to their own creative processes. It became apparent as I spoke with the children that the distinction between science fiction and fiction was not clear for them. Our discussion turned to the creative processes of scientists as they they understood them.

Melody laughed when I asked her if she found herself working as a scientist does. "No, not hardly! They create the ideas and we learn what they found out." In fact this idea was very consistent with Melody's approach in the classroom. When she pursued understanding in school science, it was the purpose of finding out what "they" say (meaning scientists). She saw this as different from her pursuit of understanding outside of Science Class, where in the natural world, she believed that she was creating some of her own ideas about the world. Amy also believed, like Melody, that in the science classroom students did not act like scientists, but learned what scientists already know. Amy did not believe that she was involved in any type of science activity outside the classroom however, and therefore did not have an example of a situation in which she pursued science like a scientist.

Martin commented that he usually preferred to create his own ideas in science. He told me, "Sometimes the teachers let you be creative." Mark remarked that "sometimes we act like scientists and other times, we don't. The times when we do are when we are experimenting with materials and equipment." Pierre also said that he felt that he was working just like a scientist when he was experimenting (doing activities). He felt that science activities were often like a maze or puzzle, and that scientists often solved puzzles and mysteries. Donnie stated that she did not believe that she was working like a scientist "because they already know all of the stuff that we are doing and we are just learning what they know." This was the only area of questioning in which I found such a distinctive split gender split of opinion among the six children in the study group, with girls commenting that they did not feel that they were working like scientists and boys commenting that at least in some ways, at times, they were.

8.5 Views on Science Learning: Past, Present, Future

Donnie was clearest about how different Science was this year compared with her experiences of the past. In her past experiences of school Science, she felt that she understood all of the information presented by her teachers, but this year she expressed the view that she was not grasping ideas, that she never quite had all of the material being presented. Amy's recollections of science in the past were of memorizing vast quantities of information--a task which she said that she disliked very much. Pierre said that he had always loved science, but particularly since last year when he produced a science fair project in which he had the opportunity to investigate dinosaurs, a topic of great interest for him. Martin commented that science "was hardly ever taught" in his previous school, and when it was, "the teachers never knew what they were doing and never let you do things like you get to do this year." Mark commented that science in the past had been much less interesting than this year's experience, and that students had been able to study much more science this year. Melody also thought that there hadn't been enough science taught in the past and that she was glad there was more this year because it "so much fun."

Despite the overall impression that science was a very welcome subject this year and that it had not been taught a great deal in the past, several of the students spoke about their encounter with science this year as being one in which they felt that science was increasing in difficulty. This was particularly true for Donnie who was quite frustrated with her lack of success in pulling ideas together. When I asked the children to tell me what they expected learning science would be like in the future, five of the six students said that they knew "for sure" that they would be dissecting a frog in grade seven. Pierre, Mark and Melody commented that science would probably become more interesting as they continued in their schooling. Amy and Donnie said that they thought it would become more difficult. Martin expected that there would be many more experiments to do, a comment made by Pierre and Mark also.

I had asked each of the children if they believed there was value in studying the topic, light in the classroom. Donnie said no at first during our conversation, then reconsidered. She stated that she wanted to become a singer and that therefore, knowing about light behavior could be valuable in her stage work because "lights will be shining on me at different angles." Melody thought that knowing about "light and how it affects you, what it does to you and what you do with it," were important understandings to be gained during the unit of study. Pierre said that he did not see any real value in knowing about light, but that now that he knew something about light, he found it quite interesting. Mark thought that knowing about light was very important because of the advent of lasers and medical experiments which use light. Amy said that she did not find the study of light very interesting, but that it might be important to know about because we use it in our houses every day, and we need also to know about lasers used in hospitals also.

8.6 Interest in Science Learning Outside of the Classroom

Martin, Pierre, Melody, and Mark spoke of an interest in pursuing experiences with natural phenomena outside of school.

Within the classroom, Martin, Mark and Pierre spoke of the enjoyment of pursing a line of thought or experimentation which went beyond or deviated from the classroom lesson, through which they discovered new ideas and insights. They also demonstrated this interest often by pursuing their own line of thought with the materials in the classroom.

Martin, Mark and Pierre also told me of their out of classroom interests in science activities. Martin and Pierre consistently followed up on activities outside of the classroom which they had undertaken during class. Martin would often share his results with other members of the class in large group discussion. Pierre tended not to share his findings with others or even the fact that he pursued activities outside of class. Mark did not build and extend the in-class activities outside of class, but spoke about "thinking about ideas" outside of the classroom and more casually of exploring different aspects of science which interested him, through magazines, television programs, and films. Further work on this topic might be undertaken to determine if these findings are related to gender.

Melody did not speak about an interest in using science equipment and materials in deviating from or going beyond the classroom lesson, although she did this more consistently than any of the other students, to the great annoyance of Mr. Ryan and her classmates. It appeared that she was not aware when she was deviating from lessons, that she simply explored what happened to be interesting to her at each moment. Her belief that she was not one who usually understood what she was supposed to in science, because the teacher did not explain thoroughly enough seemed to be a justification for her to move in her own directions. Melody shared stories with me which depicted her great delight in exploring a variety of objects in the natural world. The stories demonstrated her very keen observation abilities. However, the considerable skills, talents and abilities which she appeared to possess seemed hidden from her, her teacher and her classmates by her dominating view that she rarely had any idea what she was supposed to do or discover in science.

Awareness of the tendency and desire which students have to extend and pursue thought about the activities being studied both in and outside of the classroom would assist the teacher to guide and enhance the opportunities which students have to fruitfully pursue the extended involvement which they seek, and to share their ideas with one another. Such guidance, whether directly from the teacher, or in the form of guidelines which might accompany the classroom curriculum materials, could potentially help students to engage in creative and independent exploration, hence increasing their delight and interest in the topic being studied in the classroom.

The science fair holds tremendous potential for allowing children to both deeply explore a topic and to communicate their findings to members of the community. This experience seemed particularly appealing to all of the children with whom I spoke. Several children spontaneously shared with me their thoughts and plans about the science fair throughout the term. This interest and delight in the science fair emerged also in a review of the surveys given to the children in the class. Science fairs emerged near the top of a ranking of the children's statements "Most Enjoyed and Least Enjoyed" experiences. (Table 28)

The fact that the science fair is often viewed as an "extra frill" and a time-consuming undertaking for teachers is tragic in light of its great potential for development of ideas in science, interest and enjoyment in the processes of science and delight in communicating ideas in science. The staff of the school in this case, after several meeting in which various approaches to the science fair were considered, decided that the extra burden at a very busy point in the year was an intrusion into the ongoing science program. Although it was recognized as an enjoyable and interesting activity of the students, the teachers in the school simply could not spare the time for it. The disappointment for the children was quite intense.

Through participation in science fair projects, students are offered the opportunity to have direct experiences wth natural phenomena, to organize their ideas and to share them with other children and adults. The great interest which children have in the science fair make it an undertaking of far greater potential value in the childrens' construction of meaning in science than we may be allowing it.

Table 8-1.

"MOST ENJOYED" ACTIVITIES IN SCIENCE

	Rank Ordering of Selections
Going on science fieldtrips	1
Making and displaying science fair projects	2
Making drawings in science class	3*
Doing experiments on my own	3*
Watching demonstrations performed by my teacher	4
Thinking about new science ideas	5
Reading library books on science topics	6
Writing science reports	7
Reading the textbook	8

* Tie ranking

Chapter 9

IMPLICATIONS FOR RESEARCH AND PRACTICE

TOWARDS A PROGRAM WHICH ENHANCES THE CHILD'S OWN EFFORTS TO CREATE MEANING IN ELEMENTARY SCIENCE

9.1 The Research Project as A Constructivist Interpretation of Science Learning

As Ritchie (1982) observes, George Kelly's constructivist research approach "should be used not as an endpoint from which to make generalizations, but as a beginning from which to achieve a deeper understanding of the individual's actions in social reality. Personal construct theory examines the thoughts behind the actions of individuals (p. 31)." It is through reflection on each case that we find it of greatest value. In the case studies, theoretical constructs do not dominate the data, nor do the data dominate the theoretical basis of the work. Ritchie comments on the importance of reflection in the development of generalizations.

> An unreflective bias for generalization and theory development can result in the presentation of only a dominating set of values (constructs) as most true rather than admitting that life itself and the social realities we explore are filled with contending interpretations.
>
> p. 35

The constructivist theorist's priority is, then, to "explain social phenomena based upon an understanding which takes into account the individual." The advantage of this position, Ritchie writes, is that "we may be in a better position to illustrate how meanings have consequences for self and others." The present study attempts to present portrayals of young children learning science to allow those involved in the education of young children greater understanding of the way that a student's personal orientation to science learning affects the child's experience in the classroom.

During the initial stages of the project, an effort to understand the very individual approaches which I was observing among science students led to an investigation of the literature of current research and thinking in the reasearch area known as "learning styles." Many researchers in this field of study use pre-established categories to classify student approach to subject matter.

I found that these categories did not allow the emergence of the depth of variation among individual approaches to learning which I was observing. The categories were even less useful in helping to understand the uniqueness in individual thought and action and what was guiding the making of meaning for each person. Learning style categories seem to exist for the learning style theorist (Gregorc and Butler, 1983). In constructivist theory, the construct does not so much exist in the world as it is considered the theorist's tool in helping to explain how the individual experiences his or her world.

Whitehead (1948) referred to the overdominance of theoretical categories as the fallacy of "misplaced concreteness." He believed that this error in thinking occurs when abstractions are created and used as if they themselves provide a completely adequate and total description of phenomena. Intelligence measures have been one of the abstractions which have been used to categorize and label student ability and which have often been unfortunately used to determine nature of the experience provided for the child's growth and development. Kelly (1955) once referred to this type of misuse of such abstractions as "hardening of the categories."

The present study originated in the concern that the unique aspects of the individual as the basis for the creation of learning environments and experiences for growth and development have been too long neglected. Francis (1984) supports this view by arguing that students and teachers will be best served by a careful use of "a grounded educational psychology, based in recognition of the individuality of the learner and in fidelity to the phenomena of everyday experience."

> It also entails a weakening of the influence of the utilitarian ethic of valuing what the best outcome for the greatest number (alas for some, the comparisions of the mean values of measured outcomes), or the subjective ethic of valuing what the subject feels is best (alas for child-centered as distinguished from child-focussed education)

> in favour of a more objective valuing of the knowledge to be offerred to and acquired by the pupil. These changes, it seems to me, are inevitable outcomes of a decision to treat the verb 'to learn' as both active and transitive.
>
> p. 23

The purpose of the present study has not been merely to create a picture of the ideas which students have about the topic light prior to and after the study of light phenomena. The purpose of the study has been to construct a portrayal of the different ways that science learning is experienced and meaning is created by six individual students.

In the study, I worked closely with children who collaborated with me to help me to understand their experience. Kelly noted, regarding his discussions with and study of individuals, that the researcher, seeking to understand human conciousness, finds that the persons studied are likely to have a vague awareness of the meanings of their actions but are not explicitly self-concious about their actions. My interpretive skills as researcher have, then, been essential as the story of the meaning of science learning for each child emerged.

A prominent feature of the experience of the study was the apparent enjoyment which each person expressed in being a participant in the study, and in the connections which students were making between how they themselves construed learning events compared with their fellow students. I had been concerned, for example, that the elicitation of constructs and the rating of activities on a scale between poles of each person's construct set would be a tedious task for the students. The use of thirty-seven activities did prove to be somewhat time-consuming, and might be usefully reduced in future work. But in practice, the students expressed great enjoyment in completing the task, a task of listening to and responding to their own approaches to learning.

It has been said that as we become engrossed in educational research we run the risk of finding only that for which we may be looking (Brophy, 1985). This study emerged, however, because I began to find something that I was not looking for. It began as an attempt to understand children's ideas about the nature of light. But during pilot work with students of various ages, it became clear that the students with whom I was working not only had differing ideas about light which might be grouped into patterns of ideas, but that there were also differing ways that students approached, became involved with, and spoke about the materials and tasks that I had presented to them. It seemed important to pursue these observations to broaden our picture of student learning. I believed that our picture should include not only the ideas which students hold about light and what sorts of ideas are difficult for them to grasp, but how ideas change in the context of other important aspects of students' involvement in science learning. These aspects included students' own expectations and anticipations concerning science learning and how these affected the development of ideas in science and ideas about science. The metaphysical basis and tools of Personal Construct Theory were most appropriate for exploring aspects during a classroom study.

A very large data base, and the triangulation of several approaches allowed the corroboration of findings which formed the basis of themes for each person. If we are to consider modifying classroom practice, it is important that we have good descriptions of the ways that students live their personal orientations in their efforts to make meaning during their learning.

9.2 The Primary Importance of the Student's Participation in His or Her Own Learning

The basic assumption of the study has been, then, that students seek to make sense of their experience and that each person is guided by this basic desire to make sense of his or her experience. Frankl (1959) sees the individual's search for meaning as

> ...a primary force in his life and not a secondary rationalization of instinctual drives. This meaning is unique and specific in that it must and can be fulfilled by him alone; only then does it achieve a significance that will satisfy his own will to meaning.
>
> p. 154

If we accept the suggestion put forward by Schon (1980) and Sawada (1982, 1985) that the metaphors which we create and use to understand such problems set the pattern by which we seek solutions, then the constructivist will endeavor to develop a program which enhances the student's development and growth. Kelly's metaphor, "the person as scientist" acknowledges the person's active role in pursuing meaning and has implications for our roles in the creation of the educational environment which we offer the student.

9.3 The Uses of the Case Studies

Yin (1984) suggests that compared to other types of research, case studies have a far more diverse set of possible audiences. Potential audiences include a) colleagues in the same field; b) policymakers, practitioners, community leaders, and other professionals who do not specialize in case study methodology; c) special groups such as a student's dissertation or thesis committee; and d) funders of research. He notes that case studies are sometimes used as curriculum material and that this potential audience is often ignored in the literature.

The case reports presented here may be effectively re-written and used to introduce practicing and beginning teachers to insights into student learning. In particular, these studies may provide insight into the alternative frameworks literature, the meaning of a constructivist approach to learning science, and how students are initiated into the experience of learning science in school. The case studies, rewritten further for young children, might serve the purpose of encouraging students to reflect on their own approaches to learning, and to learn to take greater responsibility for their own learning. The students in the study group were clearly capable of this type of reflection.

9.4 An Organizing Framework: Opportunities Which Enhance the Child's Reflective Awareness and Efforts to Create Meaning in the Science Program

The alternative frameworks literature has allowed insight into the representations and images of natural phenomena which students hold. The case study reports allow us to further understand the approaches which six children use as they learn science in school, and how these approaches and strategies affect their understanding of phenomena. The reports include conversation with the actual practitioners of science learning, the children in the classroom, and has been an attempt to allow the reader to hear the story in the childrens' own words as much as possible.

Three areas of opportunity are now proposed as a framework for the development of experiences which take seriously and promote this view of the individual child as constructor of meaning in the science program. The opportunity areas are designed to assist the teacher in his or her thinking towards guiding the child to consider the nature of phenomena, and to discuss and recognize the child's orientation to science learning. The suggested opportunities are also designed to help the child to reflect upon, recognize, and value aspects of his or her own learning process, and the ways of knowing and constructing meaning in science. The opportunity areas are presented in in Table 9-1.

Table 9-1.

THREE OPPORTUNITIES FOR REFLEXIVE AWARENESS AND SELF-ORGANIZATION

A FRAMEWORK FOR DEVELOPING SCIENCE LEARNING EXPERIENCES WHICH ENHANCE THE YOUNG CHILD'S OWN EFFORTS TO CREATE MEANING THROUGH LISTENING, CONVERSING AND SHARING IN SCIENCE

I.	THE OPPORTUNITY TO HAVE EXPERIENCES WITH NATURAL PHENOMENA The provision of opportunities for the child to explore phenomena and to reflect on his or her own ideas about natural phenomena.
II.	THE OPPORTUNITY TO CONSIDER THE NATURE AND VALUE OF SCIENTIFIC EXPLANATIONS OF PHENOMENA The provision of opportunities for the child to consider scientists' explanations and ideas about natural phenomena.
III.	THE OPPORTUNITY TO REFLECT ON THE NATURE OF THE LEARNING PROCESS The provision of the opportunity to consider the ideas of other students in the classroom and the ideas held by large segments of the population. The provision of opportunities which allow the student to consider learning approaches which may be helpful in allowing him or her to take greater responsibility for learning.

I. The Opportunity to Have Experiences with Natural Phenomena

Pre-instructional experiences with natural phenomena

The movement to a "hands-on" emphasis of many curriculum programs has provided many opportunities for students to work with equipment and materials, but many science classes at the elementary level are still conducted solely through having students copy notes from the board into a "science notebook," or through reading a textbook chapter and answering questions at the end. In the program used in the present study, students engaged in an activity each day of their study of the topic. These activities were highly structured. Questions did not encourage students to suggest original or creative ideas, to share new insights, or to put together past experiences to create new ideas. A worksheet format used in the lessons was turned in to the teacher at the end of the class. This may have promoted the view that there is one single correct answer that we must always find in science. Furthermore, this answer must be indicated on the worksheet. There is a danger of students developing the notion that in science "whether I understand an idea is not so important as having the correct idea written down."

The provision of the opportunity for more initial direct experience with phenomena would allow students to have a chance for preliminary, free experimentation with materials prior to undertaking more structured activities. This might allow students to make exciting discoveries, to talk ideas over with one another, to relate new experiences to past experiences, to pose questions, and to make observations about phenomena which teachers. Many ideas discovered by children are not anticipated in curriculum materials, but are important and exciting discoveries for them. Such an opportunity would continue to encourage students to view science as an enterprise of invention, curiosity, and personally meaningful insight, gained through real interest in asking questions rather than solely as "something we learn in school now so that we'll be better able to study the harder science they give us in later years," as was suggested by one of the students in the study group. None of the children in the study group had ever looked through a microscope, and only one had had experiences with prisms in the past. The simple introduction of materials for free exploration would be an important starting point for students to begin to feel comfortable with and to have some basis in experience with materials. This could occur, for example, prior to the lessons.

Encouraging and Guiding Home studies--Ongoing Experiences with Light

Several students in the class indicated that when they went home, they not only thought about the science experiences which they engaged in in the classroom, but that they actually tried or practiced some of the activities at home which they had worked on in the classroom. This was consistently evident in the Pierre and Martin's cases. Pierre actually built his own light box at home and demonstrated its use with his younger brother and cousin. Martin told me about his follow-up tests of various dense liquids and light beams, for example, his breakfast orange juice.

A number of students chose to remain after class to explore, to experiment with materials, and to discuss the activity long after the allotted time period. Despite this obvious interest, Mr. Ryan was not aware that students were pursuing activities so extensively outside of class. These experiences which had been prompted by the children's own efforts to understand might be greatly enhanced and guided by the teacher and the curriculum. Students could be provided with optional suggestions for continuing investigations at home or for exploring new aspects of a problem given a new set of conditions to consider.

II. The Opportunity to Consider the Nature and Value of Scientific Explanations and Descriptions of Phenomena and Events

In this section some suggestions are made to provide students with the opportunity to consider and value the way scientists create explanations, and to develop an awareness that scientists create, not discover, these explanations. Of the students in the study group, only Mark explicitly understood science as an activity in which he participated to grasp understandings, but one in which he was not personally responsible for creating all of the insights which he gained during the study of science. Donnie, however, showed confusion in an apparent difficulty to distinguish her own thinking processes and ability to understand from the scientists' explanations of phenomena. She did not see her task as science student as one of grasping the scientist's explanation, but saw it as her responsibility to figure things out for herself, a task in which she continually felt a failure in the end. Mark appeared to see scientific explanation as a creation of the scientific community, but an enterprise in which he is able to participate, through his own experiences and tests. Donnie appeared to see scientific explanation as a personal product, as something which she expected that she should be able to "figure out," to create on her own. Mark acknowledged that understanding was both a product of his own experience and he showed an acceptance of the scientist's views and explanations.

The teacher might guide students towards an understanding of the nature of the creation of knowledge in science through both their participation in the processes as advocated by many of the "hands on" curriculum approaches, such as the original philosophy and intentions of the *Elementary Science Study* and *Science - A Process Approach*, and through sharing with students some of the processes by which ideas are both socially and culturally attained. A hands-on approach, by itself, is not completely sufficient, however, as was illustrated by the reform projects of the 60's and 70's.

The Nature of Scientists Knowing--The Use of Biographical and Autobiographical Literature in the Classroom

Roger Payne is an acoustical biologist, whose studies of whale songs and the migration pattern of the humpback whale are now world known. At a point very early in his career, he wrote a small booklet for the Elementary Science Study, entitled, *How Barn Owls Hunt*. The booklet describes much more than information about *How Barn Owls Hunt*. Payne tells the story of his own developing interest in barn owls, how he came to find out what was already known about barn owls, and he describes how he devised new ways to gain insight into barn owl hunting habits. Such autobiographical stories allow students to participate in and understand the struggle which scientists have in pulling together bits and pieces of information in the struggle to create explanations which explain these events. The children see that they too might participate in considering aspects of the problem, but will see the endeavor of science itself as an ongoing problem with ideas growing and changing as people approach problems with imagination and vigor and joy, arising from the scientist's own efforts and desire to understand.

Biographical sketches such as these might fascinate, inspire, and guide students to understand the approaches which are taken by those who seek to understand and the ways that they go about attaining that understanding.

The Language of Scientists--The Special Power of Convention and Meanings

Introducing some of the terms agreed upon by those involved in a specialized study helps students to grasp the nature of the creation of knowledge in science. Guiding students to create and agree upon symbol terminologies to be used in undertaking the study of new phenomena in the classroom setting may allow students greater insight through participation in the experience of the creation of knowledge in science.

Towards a New Approach to the Science Fair

A science program which seeks to guide the student to the construction and organization of meaning would take a very new and distinctive approach to the conduct of science fairs which are so frequently held in schools. In the present study, students ranked participation in the science fair as the second most enjoyable activity in the science program exceeded only by their enjoyment of science field trips.

Through participation in science fair projects, students are offered the opportunity to have direct experiences with natural phenomena, to organize their ideas about phenomena and share them with children and adults. First the science fair, or some forum for sharing isights and findings should be a more basic aspect of the curriculum, not considered as a "frill" experience. A constructivist emphasis would place at the center of the project students' personal interests in phenomena and idea creation. Students would be able to pursue a wide variety of types of projects, depending upon their interests, from the construction of models to in depth content reporting to formal experiments. The key consideration of the project would be in its interest to the student and in the opportunity of the student to share his or her ideas and findings with community members.

The Consideration of Other Views and Explanations of the World and Natural Phenomena

During the term, the science period time allottment was used for several purposes other than the light unit. Although this was a great intrusion into the already sparsely scheduled science time allotment, it provided an opportunity to consider the existence viewpoints concerning the nature of phenomena other than the scientist's.

During one science period, a writer of science spoke to the class about the process of creating her work. In the week prior to this discussion, the children had been introduced to science fiction and science fiction works in the school library. At another point in the term, an interruption of several sessions occurred when the school's Sex Education program was presented to the grade five and six students. Several sessions were devoted to this program with the participation of the school nurse and other teachers in the school. A third portion of the light unit was set aside for the visit of a native speaker-entertainer who talked with the class about the native viewpoint of humankind's relationship with the environment.

The native speaker's presentation presented an extremely rich opportunity to discuss with students the value of alternative views of the world and phenomena. Students might consider the value and utilty of the scientific explanation both through their participation in the process by which we make observations, collect information, and put forth explanations. And through considering other ways that others value and explain their world, students can be made more aware that the scientific viewpoint is one of many valuable ways of explaining the world, and that it holds great utility in it explanatory power. Other viewpoints which explain the phenomena of the natural world may be considered as potentially useful also, with clear understanding of the sources of knowledge and the means by which these explanations came into being. The purpose is not to devalue either approach to understanding, but rather to understand the tentative nature of scientific explanations. A careful, sensitive treatment of such issues would result in the child's valuing the scientific explanation, but also realizing that the scientific explanation may be counter to other ways of conceptualizing the world.

III. Opportunities To Reflect on the Learning Process

Other opportunities are presented which may help students to develop reflexive awareness during science learning, that is, to become more conscious of the learning process itself, and to value and build upon their own efforts and approaches to learning.

A. The Classroom Profile: Learning About How Others Are Thinking About Phenomena

One means by which children can be guided to consider the usefulness of others' viewpoints is by sharing their ideas with fellow classmates, and at a later time, considering their own ideas alongside those put forward by scientists. During the study, I invented *The Classroom Profile*, a device which has shown very good potential as a means of highlighting and emphasizing concepts which have been found to be very difficult for science learners to grasp. The *Classroom Profile*, shown in Table 9-2, allows

Table 9-2.

THE CLASSROOM PROFILE

STUDENTS IDEAS ABOUT 'THE BROKEN PENCIL PHENOMENON'

EXPLANATION (Ranked)	Name (For Teacher Reference)	Number of Students
1. "The water makes it look broken."	Phyllis Jessica Lorene Di Donald Carlo Monty Ching	8
2. "Water bends the light rays."	Stella * Mark Sally James	4
3. "The shape of the beaker makes it look broken."	* Pierre Leslie Rose	3
4. "The water and the beaker make it look bigger."	Kim * Melody * Amy	3
5. "The water and the beaker act as a magnifier."	Raini Hyon Sin	2
6. "The water acts as a magnifier."	* Martin Arnie	2
7. "Because we tilted the pencil."	Arcala	1
8. "The light rays and the glass make it look broken."	* Donnie	1
9. "The light rays do it."	Denise	1
10. Descriptive statements only	Susan Karin Annie	3
11. Unusual water ideas	Rochelle Danny Trellis Lewis Michael	5
	Total	33

* Students in the study group

sharing of the thinking processes of a class of students as a way of 1) Helping individuals to become aware of their own ideas about the nature of phenomena and 2) Comparing their ideas with the ways that other children in the classroom are thinking about phenomena. Two class profiles were shared with the children during the latter part of their unit of study. In the preparation of each profile, students were asked to respond to a simple question or questions about current ideas which they were studying. I built the first profile from students' written response to a question asked after the a lesson on refraction. A diagram was placed on the top of the question sheet showing the broken appearance of a pencil in a beaker of water. The students answered the following question: "On Wednesday, you observed a pencil placed in a beaker of water. What is your explanation for the unusual look of the pencil in the beaker of water?"

I collected the students' answers and found that they could be placed into several groups. These groups were placed on the class profile chart and the names of the students providing explanations were listed next to each group. Student names could be either used for teacher reference or could be shared with the class, depending on the teacher's preference. I chose not to show students' names along with ideas. The number of students making similar statements was noted allowing a rank ordering of the responses. This particular profile mades it very clear to students that the most popular response (shown by the tabulation of statement groups on the chart) is not always the response which most closely resembles the scientist's. The Classroom Profile helps the teacher to understand how individual children are thinking about the ideas presented to them and shows how groups of students are thinking along similar lines. Other information is also available. In this profile, three students made descriptive statements when they had actually been asked to provide an explanation. The distinction between an explanation and a description could be made clearer to these students. I found the sharing of the profiles to be of great value to the students. They find it interesting to see the ideas of fellow students and they enjoy discussion and reconsidering their own ideas. In the process of exploring the ideas with the students in the study group, the children noted that several categories could be combined further so that there were several basic ideas held by members of the class which students were considering. Martin asked me which one was the correct idea. He recalled that Mark had been told by Mr. Ryan that he had the correct idea, and wondered what Mark had written on his sheet. A discussion about the usefulness of the various ideas continued from the sheet with the students in the study group. Only Mark had given the correct idea (Number 2 on the profile chart). Several of the students remarked on the nonsensical nature of his idea that water was bending light rays and that light rays were coming from the pencil. In the discussion which followed, the students brought in several of the ideas proposed by Mr. Ryan, they challenged one another's viewpoints, and reiterated their own experience of the activity. Melody asked me, "What would a scientist say? Would he say any of those?" When I answered her question, Martin asked me to explain how water could possibly bend light, and I was able to reiterate for him that point in the explanation which he showed that he was having difficulty grasping.

Videotapes

Videotapes hold a great potential for building upon the intense interest which students show for one another's thoughts, ideas, and approaches to science learning. A series of videotapes presenting the strategies of different children learning science, perhaps of students not known to the class could be developed and presented to students. Viewing these tapes would guide students to reconsider their own and others' approaches to learning, to become more conscious of their abilities to take a more active part in their own learning, and to develop strategies which are effective and compatible with their own interests in, style and approach to content. This interest in one another's successful strategies has been documented in the case studies. Amy, for example, was able to recount the steps by means of which Mark had actually grasped an idea which no one else in the class had been able to understand. In this instance, Mark's singular grasp of the concept literally turned the class into a buzz of thought, highlighting the ideas and precipitating the grasp of the new idea for many students. The children in the classroom were interested in one another and in how students succeed in their studies. This was also apparent from the constant references throughout my conversations with students to other children in the classroom and through reference to brothers and sisters, or even parents' approaches to subject matter.

Many of the children in the study group made reference to how fellow students had helped them to grasp an idea, or how they had organized their approach to study. Melody held an unusually complete grasp of the activities of nearly every small working group in the classroom. Though her interest did not appear to be in knowing about the concept, light, the activities of other students intrigued her and drew her into some understanding of meanings which were important in the development of ideas in the lesson. Because of her natural interest in the social functioning of the class, she began to grasp and become interested in the concepts being presented in the lessons. This ongoing discussion with fellow students and the teacher has been very useful in the children's efforts to grasp the concepts being presented in the unit.

Small group interaction

Perhaps the strongest and most effective form of 'making sense' of learning science from the perspective of the students in the study has been the small group interaction which has been described in the case study reports. This experience offers a powerful opportunity to provide students with guidance in the organization and improvement of their own small group interaction. Learners can be encouraged to reflect upon small group learning processes to enhance the effectiveness of this procedure in the classroom to help children develop and extend concepts. All of the children participating in the present study expressed enjoyment of, and highly valued the opportunity of working together. All said that given the choice of a chance to work with others or on their own, their preference was usually to work with others.

As demonstrated in the case studies, the childrens' various personal orientations to science learning were lived through the interaction during these sessions. For Martin, for example, the group sessions offered an opportunity to receive assistance in reading the worksheet.

Students may become more aware of the value of the teaching role of the group itself and may consider ways that they might help one another to learn more effectively in the group. This seemed particularly important on a number of occasions, when students expressed a reluctance or fear of asking the teacher questions. Donnie's experience was reflected in one of her personal constructs concerning asking Mr. Ryan for help, "Being embarrassed, about to get into trouble."

There were instances, although they were more rare, when students did not want to give help to others when they felt that other students wished only to reap the benefits of their hard or clever work. Amy often expressed the sense of "being ripped off" by Melody. "She just copies my paper. She doesn't do anything!" Amy was far more willing to share ideas with Martin, who worked with her during the activity to come to some understanding.

The children's efforts can be guided in the small group work by encouraging them to reflect on the dynamics of group work, how they might better listen to one another and consider the ideas that group members put forth to everyone's benefit. Mark's group experience was an interesting case in point. When he very suddenly realized the explanation for the appearance of the coin in the saucer activity, he voiced his idea several times to members of his group. Group members did not understand Mark's explanation, and ignored his comments, continuing to talk about the activity among themselves. If teachers are able to guide students to reflect on how often and how well we listen to the comments and suggestions of group members, they may become better listeners with one another. Students might be encouraged to consider the value of others special talents in the group as useful resources. Students might also be encouraged to consider that their own contributions are of value even when they do not seem to make sense to others at first.

Pierre's view of himself as a contributor to the small group discussion was originally quite negative. He saw himself as one who was continually struggling with ideas and who needed to get help from others. On one occasion, Pierre realized that he was the only person in the group who had grasped the notion of the task to be accomplished in the group. He seemed surprised to find himself for the first time as the giver of information, as the helper in the group. When other members listened to Pierre, he seemed renewed with excitement in his sense of himself as a student of science.

The opportunity to work in groups allows children the opportunity to explore together in a natural way. The experience could be enhanced through encouraging student to become more conscious of the processes which they are involved in together. Developing awareness of the various ways that children construe this experience will allow the teacher to suggest good working groups based upon learners' assisting one another in the creation of meaning. Direct suggestions to the children concerning the value of the group activity for the experience of creating meaning would focus less upon rules for keeping quiet and finishing worksheets, and would help students focus more upon observing how others are creating meaning in their work.

In addition to considering other students' interaction in the small group, students might be encouraged to reconsider their own individual approaches to learning in the small group setting. And here we come up against one of the great barriers to the development of the type of student responsibility and reflexive awareness which is being suggested here. The pressures of an educational system which values and rewards the attainment of correct ideas only and encourages a competition which rewards individual achievement often does so at the expense of cooperation and sharing which might benefically occur within the group. When groups are working well, members are sharing insights and understanding, and are teaching one another.
teaching one another.

Learning to Ask Questions

Joan Tough (1979) notes that it is often assumed that children already know how to formulate questions, as they frequently ask questions of teachers in classrooms. But as Tough (1979) points out, their questions are usually those which ask for permission, for directions, and for instructions. Less often do children ask questions which seek further knowledge about a subject, or request explanations.

In Tough's (1979) view,

> This may be because they [children]learn that children are not generally expected to ask questions of this kind; that adults' decisions, particularly teachers' decisions, are not open to questioning. Even when children have learned to seek information from parents and others at home, they may learn that such questioning is regarded both by teachers and children as inappropriate in school.
>
> p. 125

Students will benefit from guidance in discovering the types of questions which best assist them to access information, and when and how they might best ask questions of themselves to uncover information through own efforts. They might be encouraged to practice using specific types of questions in both large and small group settings. In fact, the students in Mr. Ryan's class were learning to ask a variety of questions as part of a reading program which was being used by several teachers in the school. Students were actually learning to ask questions using Bloom's Taxonomy as a framework. As they read and discussed stories, they systematically practiced writing questions about the stories which reflected the various cognitive levels. Factual questions during one lesson, evaluative questions during another, for example. The students then asked one another the questions which they had developed.

During one of the light unit activities the children predicted the results of reflecting a light beam from variously angled mirrors. Pierre commented to me after this lesson how similar the task was to writing prediction questions during his reading lesson. The opportunity to reflect upon and organize ideas through the use of questions could be very effectively related to small and large group activities during the science program.

Another means of helping young children recognize the value of different types of questions is to discuss and practice interviewing people (advocated by Tough, 1979, p. 126). An application of this approach is developed in the energy studies unit, "The Energy Sleuth Kit" (Shapiro, 1982, 1986). In the activity, "Calling Key Witnesses," students interview various witnesses who may have information about the use and possible waste of energy on the students' school site. The students prepare their questions in advance of the visit of the "key witness" and share them with other members of the class. The goal is to develop questions which will allow the students to achieve a maximum amount of insight and information through the types of questions which they ask. Each individual in the class makes a unique contribution to this effort. In this way, the individual members of the class make a difference in contributing to the groups' discovery of the types of information which can be acquired through the use of good questions. Such an approach enables students to develop the skills needed to meaningfully question another person. These skills can be applied as students question one another, their teacher, and as they participate in the class's large group discussions.

Approaches Which Help Students to Organize Their Thoughts

During the unit, I presented to the class an approach to help them organize their ideas about light, called "concept mapping." Concept mapping is based upon the research and thinking of J. Novak and D. B. Gowin (1984), who developed their work from the learning theorist David P. Ausubel, which suggests an approach for representing the connections between ideas in a specified body of knowledge.

In our preliminary discussion, I spoke with students about their responsibility for learning. I told the class that I believed that "it is Mr. Ryan's responsibility to teach students and it is the student's responsibility to learn." I told them that I was going to show them one way that they might organize their ideas to make learning easier and more effective." At this point I was greeted with great interest from the children. They seemed very interested in learning, and were anxious to begin. I told them that I had learned that their teacher, Mr. Ryan, was an avid astronomer, and that I had asked him to give me an introductory lesson in astronomy. I took notes during his talk and afterwards constructed a concept map to help me to organize the ideas which he had presented. On a large sheet of paper, I showed the class the concept map which I had made which linked the new ideas together. We looked at the map to see how concepts were linked with connecting ideas or propositions.

I showed the children examples of concept maps which children their own age and younger had produced (see Appendix C). As they examined the concept maps, I showed how the maps provided their authors with a type of visual road map (Novak and Gowin, 1984) showing the ways that meanings can be connected as they are learned.

Novak and Gowin refer to the connections between concepts linked by a word or phrase to form a proposition. They state that these links between concepts are intended to represent meaningful relationships between the concepts and contrast this with the all too typical rote memorization of terms and concepts common to science learning. The creation of concept maps was presented then as a search for meaningful relationships among concepts presented. Mr. Ryan allowed me to spend a class session reviewing the concepts and ideas presented to date in the light unit.

The concept mapping session was a particularly valuable session for several pairs of students who chose to produce a map together. Not only were connections made among ideas which were then made more concious to the children, but they were able to see one another's concept maps and see how other individuals' unique views of content differed from their own. The teacher is also able to see where connections may be inaccurately or inappropriately made, or where complete ideas might be missing altogether.

Using concept mapping or similar schematic representations such as outlines, diagrams or flowcharts would require of the teacher a clear understanding herself of the connections between and among ideas presented in the lessons. The procedure also requires a teacher who is committed to encouraging students to take greater responsibility for their own learning, one who will allow students both the preliminary period of learning required to understand how to construct these learning devices, and who will provide the time for students to make connections among ideas on a regular basis.

It is clear from the analyses of the case reports that individuals possess different talents and interests in their pursuit of understanding in science as seen in their personal orientations to science study. Students should be given a range of options and be encouraged to use creative approaches in the form and content of their representations. Britton (1979) reiterates this viewpoint in his study of the teaching of students who are making plans for writing. What is an effective and valuable planning procedure for one individual, for example, the preparation and use of an outline, may be stultifying and obtrusive for another. The teacher interested in encouraging children towards self-organization might find these representational tools useful in helping them to become more conscious of their own learning. The teacher must plan carefully and must be prepared to spend a good quantity of time in helping children to take greater responsibility for their own learning.

EPILOGUE: TOWARDS SCIENCE LEARNING WITH THE PSYCHE LEFT IN--A SCIENCE FOR THE SPIRIT

> The human mind is a mystery. To a very large extent, it will probably always be so. We will never get very far in education until we realize this, and give up the delusion that we can know, measure, and control what goes on in children's minds. To know one's own mind is difficult enough.
>
> John Holt
> _How Children Fail_
> p. 156

Indeed, the mind is a mystery and each child's approach to learning is highly individual. Each person has his or her own unique approach to creating meaning in learning and this approach can be seen reflected in patterns of thought and behavior. But if a child is to be successful in our educational system he or she must adapt to the goals and purposes of teachers and the school curriculum. There is sometimes a great struggle as the child attempts to adapt to the learning experience and create his or her own meaning at the same time. Research studies of this process have traditionally left out the individual and the spectrum of emotions which guide the person towards the creation of meaning. Through focussing upon the person's ways of striving for meaning and expression, I have constructed individual stories of each person's learning orientation which evolves over a period of time and forms a manifold--a network of events, behaviors and activities. Though it may be true there are various patterns which link individuals and which allow us to see how human beings share many characteristics, this study has attempted to show the unique aspects of children as each one seeks to understand. The study is intended to preserve both the sense of individuality and the sense of shared or common aspects as each child is both a social being and a unique person. Following this I have proposed a framework for guiding the child in science education which recognizes and values the person's own expressive efforts, a science education which values the emotions and the spirit of persons. The study has allowed me to place the individual at the forefront and to reconsider the ways that we listen to children as they study school science. By valuing children's own efforts to learn and tell us what they are learning, we may help students to feel less alienated in the science learning experience. A most important aspect of this process, however, is that the child develops and understanding and awareness of his or her own approch to learning. Ultimately this would help make it possible for the person to be a more expressive and full participant in the learning experience. This sense of fullness of participation and the fact that the student recognizes that he or she has some measure of control over events and experience is essential in a person's development and efforts to become a fulfilled complete human being. As Kelly (1955) wrote, his entire theory was designed to understand the fullness of this experience of being human:

> The psychology of personal constructs is part of the psychologist's protracted effort to catch the sense of man going about his business of being human and what on earth it means to be a person.
>
> p. 8

Whereas other theories define learning as a special form of human behavior, Kelly (1969a) has regarded it as "human behavior at its most typically human."

The attempt to gain and present a more complete picture of the experience of the child arises from a concern that many current studies have tended to disembody the experience of the person from learning. Although many of the studies have provided us with a useful set of the generally incorrect ideas held by the majority of students in classrooms, they give us little understanding of how the student who does grasp concepts and succeeds in our classroom conceives of the experience as contrasted with the student who may struggle, fail, and emerge with a low sense of competence in science, or who may become completely alienated from science and any further work in science.

The development of the six case study reports has been an attempt to understand the individual pursuit of meaning during the experience of learning science in the elementary school. A variety of approaches have been used in conducting conversations with six very different children, whose unique orientations to science study are reflected in their thought and action in the classroom. Key to the understanding of each student has been an attempt to convey the connection with what is referred to by Gruber (1978) as the emotional substratum, a missing gap in many studies which deal with cognition. Gruber suggests that understanding this powerfully influencing set of factors begins with recognizing the significance of individual experience.

> You have to find some other way through the philosophical maze, a way of leaving room for the individual to make his or her own decisions, inventions, constructions, a way to make a difference so that if this person or that one had not existed, something would not have have happened the way it did. The individual matters.
>
> Gruber (1978, p. 136)

The individual's own efforts matter. Seeing the student as co-architect of learning along with the teacher implies that we consider the student capable of recognizing, understanding and redirecting some of his or her own actions and study behaviors during science learning. In our efforts to help the student enhance his or her effectiveness, stress is placed upon making the student aware of the value and impact of such factors as social and collaborative aspects of activities in learning science in school. Such factors must be included in our understanding of the learner's experience, and it is hoped that these accounts can promote awareness and discussion among learners, teachers, and curriculum writers. The student's personal orientation has been found to powerfully guide the development of his or her image of self as learner of science in the classroom learning environment.

The suggestions for future direction in this work have sought to address the question posed by Margaret Donaldson (1978), which is fundamental to the constructivist position:

> So what makes us stop and think about our thinking -- and thus makes us able to choose to direct our thinking in one way rather than another?
>
> p. 97

In her consideration of this momentous question, Donaldson puts forth the hope that reading in schools be taught in such a way as to greatly enhance the child's reflective awareness, not only of language as a symbolic system, but of the process of his or her own mind. From the very beginnings of schooling, she argues, we may start to help the child towards some degree of understanding of the general nature of the learning activity which he or she will engage in during his or her learning in school, an approach which builds upon the child's sense of the possibility which reaches beyond things as they are to how things might be (p. 97).

What is required is new understanding and awareness. The teacher must have a deep understanding of the nature of science and the processes by which knowledge is created. The teacher must be attempting to understand and become aware of the ways that students are thinking about phenomena. As Smith (1974) cautions, such an approach to teaching is very demanding. It requires

> ...a rejection of formulae, less reliance on tests, and more receptivity to the child. Its main demand is a total rejection of the ethos of our day -- that the answer to all of our problems lies in improved method and technology and of the emphasis on method that pervades almost all of teacher training.

I found, through observing and conversing with the children in the study described here, that as I became a better listener, the children with whom I spoke became more responsive, sharing more and more of their thoughts and feelings about their experience with me. As I became a better listener, the expectation seemed to be developing in the children that what they had to say was important. Because the children knew the purposes of my study, they were aware that what they had to say was not only for me to hear, but that I wanted to share their ideas (anonymously, of course) with teachers, curriculum developers, researchers and student teachers. I found also, that the children became very interested in me, the listener, as a person. They would often ask me what I thought of an idea or an insight, and several asked if I would help them with some of their other school work. Possibly the most important aspect of this approach to research and teaching is the demonstration that our sincere interest in what students have to say may create the expectation in them that their ideas, thoughts and feelings are valued by us. With this expectation, students may become more receptive to, and place greater value on, the learning that we attempt to guide them towards accomplishing.

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APPENDIX A.

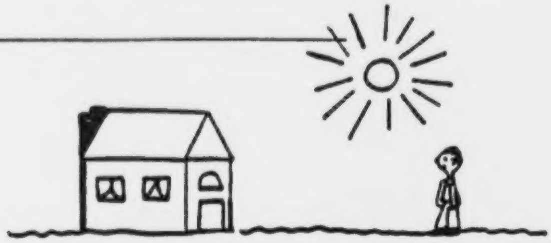
Survey of Student Ideas About Light Given Prior to the Light Unit

APPENDIX A.

Survey of Ideas About Light Prior to the Light Unit

Name ______________________

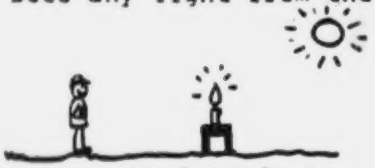
1.



The boy in the picture sees the house. Draw in arrows to show how the light from the sun lets him see the house.

Check yes, no or I don't know.	YES	NO	I DON'T KNOW
2. When you see the sun, does any light go from the sun to your eyes?	____	____	____
3. Does the sun make its own light?	____	____	____
4. When you see the moon, does any light go from the moon to your eyes?	____	____	____
5. Does the moon make its own light?	____	____	____
6. When you see a book, does any light go from the book to your eyes?	____	____	____
7. Do a cat's eyes make their own light?	____	____	____

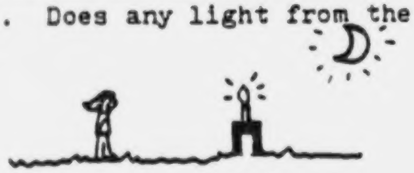
8. It is daytime. Does any light from the candle reach the boy?



____yes ____ no ____ It depends on how bright it is. ____ I don't know.

---

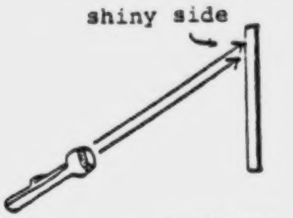
9. It is nighttime. Does any light from the candle reach the girl?



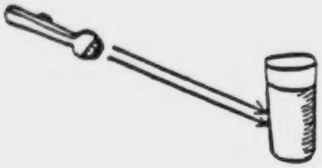
____yes ____ no ____ It depends on how bright it is. ____ I don't know.

Page 2.

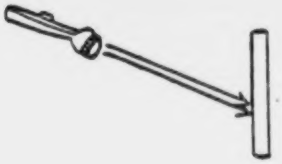
For each of the four objects below, use arrows to show what happens to the light rays coming from the flashlight.



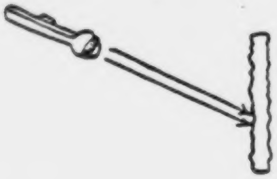
A mirror



A glass of water



A piece of clear glass
(like window glass)



A flat rock

APPENDIX B.

Examples of Materials Used in Conjunction With Interviews To Understand Ongoing Development of Ideas About Light

Name ____________________

Date ____________________

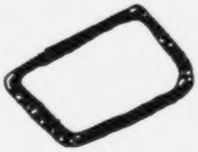
Imagine a lamp or flashlight above each object.

Does light from the lamp reflect from any of the objects?

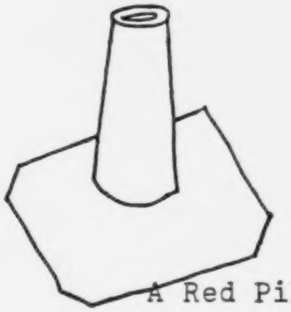
_____Yes _____No

If you have checked 'Yes' also place a check by those objects which reflect light.

The Floor

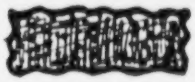


A Mirror



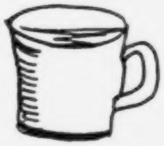
A Red Pilon

A Piece of Black Cloth

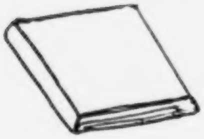


A Brick

A Piece of Carpet



A Cup



A Book

Name ____________________

Date ____________________

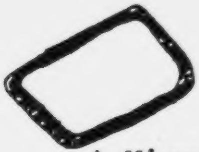
On the floor I have placed the objects drawn below. We have the light off in the room but the blinds are open.

Does any light reflect from any of the objects?

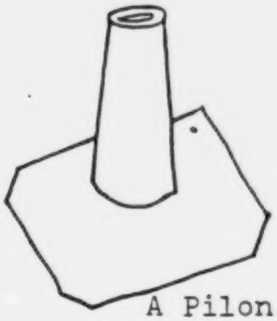
_____Yes _____No

If you have checked 'Yes,' also place a check by those objects which reflect light.

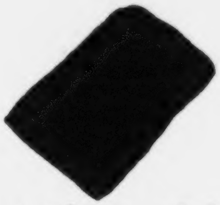
The Floor



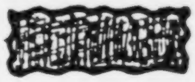
A Mirror



A Pilon

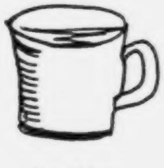


A Piece of Black Cloth

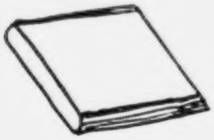


A Brick

A Piece of Carpet



A Cup



A Book

Interview Record

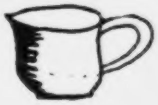
Ongoing Evaluation: Ideas About the Reflection of Light

Name ____________________________

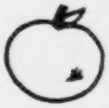
Date ____________________________

Check the objects which you believe that light reflects from or bounces from. Ask for any help that you need to complete each item.

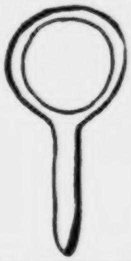
1. A cup



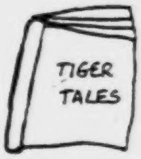
2. An apple



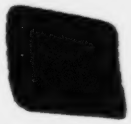
3. A mirror



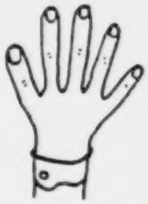
4. A book



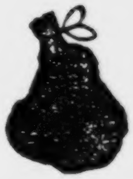
5. A piece of black cloth.



6. A hand



7. A black plastic garbage bag.



8. We learned about the light meter today. What does a light meter measure?________________________________

____

____

Light Unit Evaluation

Name ______________________________

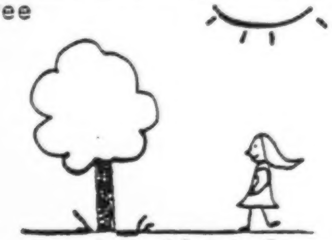
Date ______________________________

1. What I liked most about the light unit was ______________
____
____

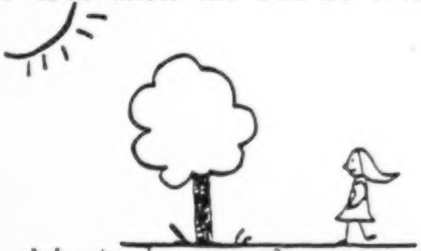
2. I am still wondering ______________________________________
____
____

3. What I found difficult to understand was __________________
____
____

4. Use arrows to show how light from the sun helps the girl to see the tree



5. Use arrows to show how light from the sun helps the girl to see the tree when the sun is behind the tree.



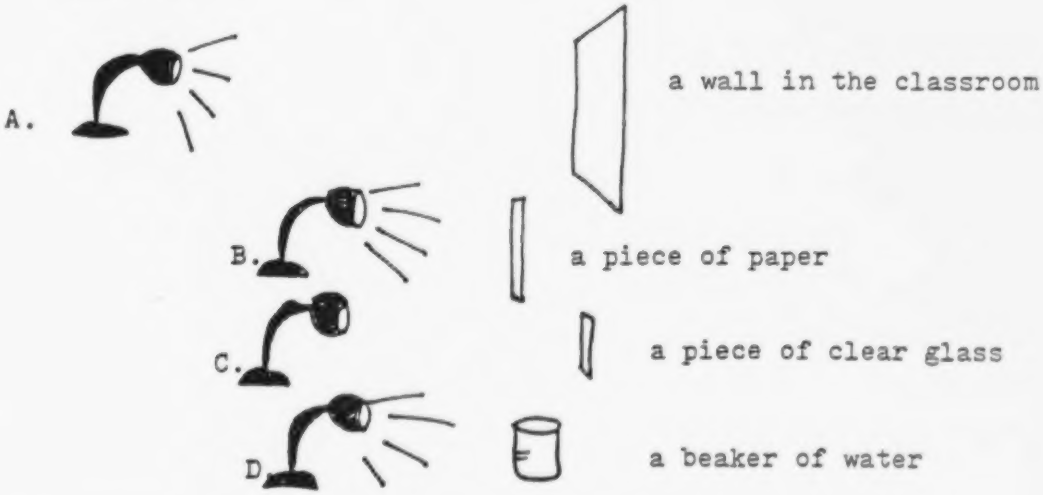
6. Check the objects in our classroom that light reflects from.

___ a desk
___ a pencil
___Ms. Shapiro
___ a hand
___ the blackboard
___ the floor
___ a pure black cloth

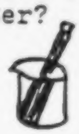
7. Before our prism activity, had you ever looked through a prism?

8. We all saw the rainbows with the prisms. How are these rainbows formed? ____
____

9. Draw arrows to show what happens to light shining onto the object shown. If you cannot draw arrows, write down what happens.


A.
a wall in the classroom
B.
a piece of paper
C.
a piece of clear glass
D.
a beaker of water

10. What is your explanation for the pencil's unusual appearance in the water?



____

____

____

11. Check to give your evaluation of the light unit.

a.

I really enjoyed it!	I enjoyed it.	It was okay.	I didn't enjoy it.
____	____	____	____

b. I learned:

A great amount!	Quite a bit.	A fair amount.	Not much.
____	____	____	____

c. The activities were:

Extremely easy.	Fairly easy.	Not easy/Not difficult.	Difficult
____	____	____	____

d. I understood:

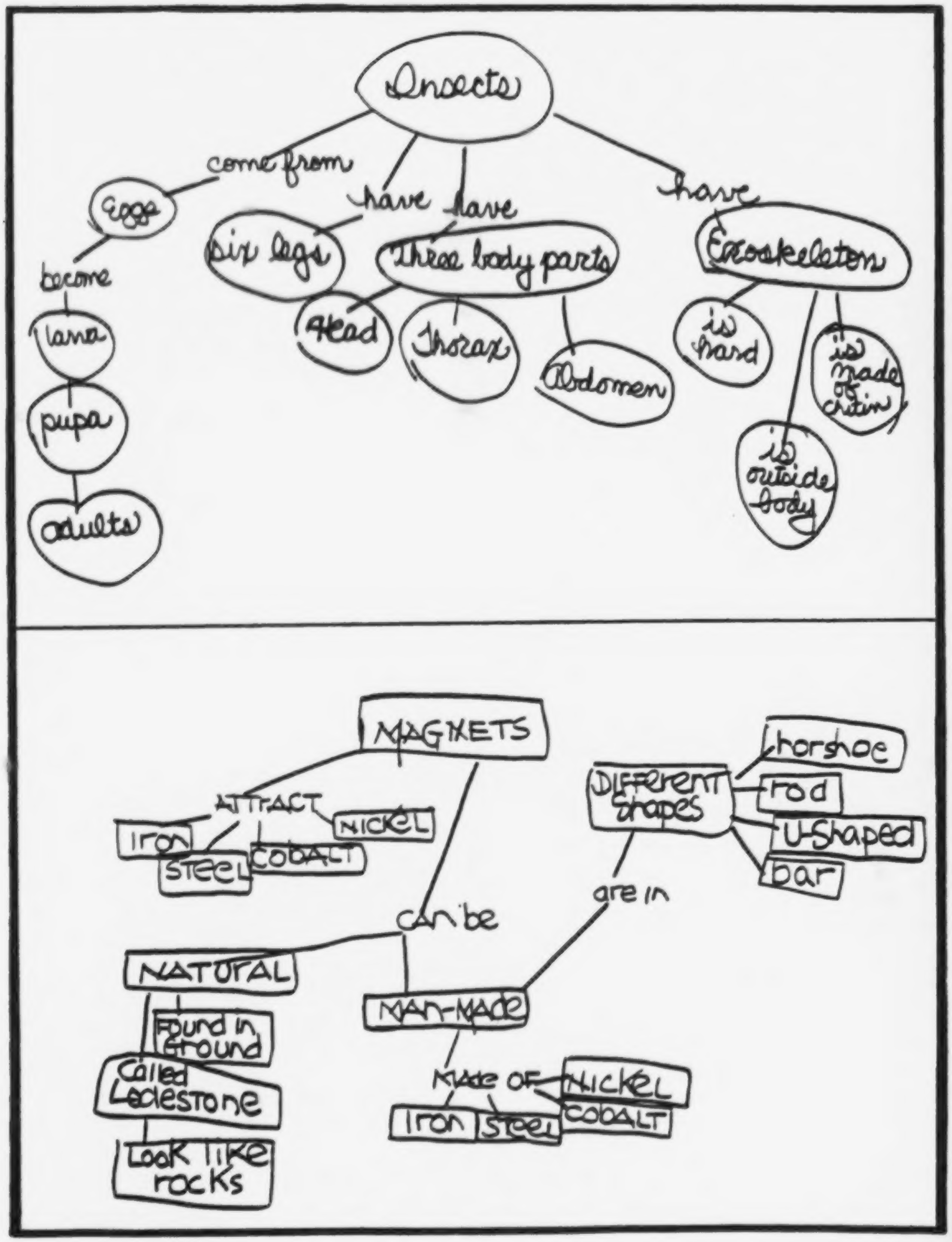
Everything.	Almost everything.	Some ideas.	Very little.
____	____	____	____

APPENDIX C.

Sample Concept Maps Drawn By Grade Four and Five Students

APPENDIX C.

Sample Concept Maps Drawn By Grade Four and Five Students


Insects
come from
Eggs
become
larva
pupa
adults
have
Six legs
have
Three body parts
Head
Thorax
Abdomen
have
Exoskeleton
is hard
is made of chitin
is outside body
MAGNETS
ATTRACT
Iron
STEEL
COBALT
NICKEL
can be
NATURAL
found in Ground
Called Lodestone
Look like rocks
MAN-MADE
Made OF
NICKEL
COBALT
Iron
STEEL
are in
DIFFERENT Shapes
horshoe
rod
U-Shaped
bar